FICIAL
ES
D
PTION
ABS

57,
Ernest.
~~18/-~~
H. XLIX
20/l

ARTIFICIAL LIMBS
AND AMPUTATION STUMPS

ARTIFICIAL LIMBS
AND
AMPUTATION STUMPS

A PRACTICAL HANDBOOK

BY

E. MUIRHEAD LITTLE, F.R.C.S. Eng.

CONSULTING SURGEON TO THE ROYAL NATIONAL ORTHOPÆDIC HOSPITAL; SURGEON TO THE ROYAL SURGICAL AID SOCIETY; VISITING SURGEON UNDER THE MINISTRY OF PENSIONS TO QUEEN MARY'S CONVALESCENT AUXILIARY HOSPITAL AT ROEHAMPTON; MEMBER OF THE ADVISORY COUNCIL AND ONE OF THE MINISTER'S ADVISERS ON ARTIFICIAL LIMBS

WITH TWO HUNDRED AND SIXTY-SEVEN ILLUSTRATIONS

LONDON
H. K. LEWIS AND CO. LTD.
1922

10043754

12689

PREFACE

MONOGRAPHS by English writers on the subjects treated of in the following pages are rare. As far as my knowledge goes there are only the monograph on "Artificial Limbs," a small, thin octavo volume by H. Heather Bigg, published in 1855, which was reproduced with some additions in "A Manual of Orthopraxy" by the same author in 1877, and a translation of the French handbook on "Artificial Limbs" by Broca and Ducroquet, edited by Major R. C. Elmslie, which appeared in 1918 among the series of Military Manuals under the general editorship of Surgeon-General Sir Alfred Keogh. This work gives a good insight into French practice, as well as editorial notes on British methods. On "Amputation Stumps" there is the excellent small book by Mr. Martin Huggins, published in 1918, in which are embodied the results of his experience at the hospital for the amputated at the Pavilion at Brighton.

It seemed to me that it would be worth while to record the conclusions which have been reached as the result of six years' experience in the treatment of amputation stumps at the Royal National Orthopædic and in various Red Cross hospitals, and in the prescription and supervision of prostheses at Queen Mary's Convalescent Auxiliary Hospital at Roehampton. During this period some 25,000 cases of amputation have been dealt with at Roehampton, the greater part of which have been under my personal care, while as an adviser on artificial limbs to the Minister of Pensions I have had opportunities of inspecting the various prostheses which have been submitted for approval.

In this book no pretence is made of offering a complete and encyclopædic work on the subject, such as has been produced by thirty authors in Germany under the title of "Ersatzglieder und Arbeitshilfen," etc., published in Berlin in 1920. I have contented myself with a description of British practice with few references to foreign methods, which, however, differ little and not often advantageously from our own.

The author of a work of this kind is in some danger of making the book a compilation of limb-makers' catalogues. This danger I have tried to avoid, but at the same time I have availed myself freely of permission accorded by various limb-makers to use their illustrations, for which I now take pleasure in thanking them. Those which are here represented are taken as typical, and it must not be supposed that equally good prostheses of similar types are not produced by other makers.

Those illustrations of which the sources are not stated in each case are from sketches or photographs by the writer.

At the time of writing the battle of the legs is still raging, and at the moment aluminium seems to be in the ascendant over wood and leather; it must be remembered, however, that the two latter have been exposed to a length and severity of proof to which it has not yet been possible to subject the former. No matter which—if any—wins, the competition can be productive of nothing but good to the amputee.

I take this opportunity of recording my indebtedness to the Director-General of Medical Services of the Ministry of Pensions, Sir Lisle Webb, K.B.E., C.B., C.M.G., D.G.M.S., for permission to use drawings and diagrams and other material belonging to the Ministry. To Mr. Harry Longmate, A.M.I.M.E., late Superintendent of the Experimental Workshop, I am indebted for much information and help, as I am also to the representatives—too numerous to mention—of the various limb-making firms employed by the Ministry. I have to thank my daughter to whose labours I owe the typescript and the index, and my son for reading the proofs.

E. MUIRHEAD LITTLE.

LONDON,
February, 1922.

CONTENTS

ERRATA

Page 57, last line, *for* "1 and 2," *read* "42 and 43."
Page 89, line 9 from bottom, *for* "as," *read* "in."
Page 111, fig. 97, *for* "above elbow," *read* "below elbow."
Page 114, lines 6 to 8, *for paragraph* "The fingers" *to* "joints," *substitute* "The thumb is rigid, but the fingers are formed of coils of strong steel wire, backed with leather. They can be flexed into the palm by movements of the lever, and are locked in all positions."
Page 162, line 8 from bottom, *for* "discarded" *read* "fitted" *and after* "healed," *insert* "is discarded"
Page 221, last line, *for* "see fig. 209," *read* "see fig. 210."
Page 238, legend to fig. 217, *for* "snivel," *read* "swivel."

contented myself with a description of British practice with few references to foreign methods, which, however, differ little and not often advantageously from our own.

The author of a work of this kind is in some danger of making the book a compilation of limb-makers' catalogues. This danger I have tried to avoid, but at the same time I have availed myself freely of permission accorded by various limb-makers to use their illustrations, for which I now take pleasure in thanking them. Those which are here represented are taken as typical, and it must not be supposed that equally good prostheses

tives—too numerous to mention—of the various limb-making firms employed by the Ministry. I have to thank my daughter to whose labours I owe the typescript and the index, and my son for reading the proofs.

E. MUIRHEAD LITTLE.

LONDON,
February, 1922.

CONTENTS

I
v
v
c
f
t
p
t
a
S
t
t
y

li
b
I
a
h
n
R

ARTIFICIAL LIMBS

CHAPTER I

HISTORICAL

AMPUTATION for injury or disease of the extremities has been practised for many centuries, and no doubt dates from prehistoric times. Some forms of prosthetic appliances have probably been used for nearly as long. Ancient history affords an example of a prosthesis having been used at the beginning of the fifth century B.C. Herodotus tells us that Hegesistratus, a native of Elis and a seer, was thrown into prison and condemned to death by the Spartans. He escaped by amputating the foot by which he was confined, and made his way to Tegea, thirty miles away, where he fitted himself with a wooden foot. The amputation was evidently very low down (ἀπέταμε τὸν ταρσόν). However crude the prosthesis was, it allowed him to continue his profession of seer, for he was present at the battle of Platæa in 479, though in the Persian interest. He was still travelling as a prophet when the Spartans seized him at Zacynthus and put him to death (Herodotus ix. 37). The oldest extant example of an artificial leg is at present in the museum of the Royal College of Surgeons of England. It was found in a hitherto undisturbed tomb at Capua in Italy, together with some vases, which from the style of art were almost certainly made not later than the year 300 B.C.

The artificial arm made in 1509 for, and worn by, Götz von Berlichingen is in the Nuremberg Museum and in good order. It has been described in detail recently in the *Zeitschrift für Deutsche Ingenieure.* It is made of metal and has articulated fingers, and is said to have been so useful that its wearer could strike a harder sword-stroke with it than he had been able to do with its natural predecessor (see Medical Supplement to the *Daily Review of the Foreign Press,* vol. i., No. 6, p. 156). This hand, the mechanism of which is shown in figs. 1 and 2, was not one of which the fingers are capable of active movements, but they are adjustable and can be fixed in the required positions. All the joints of the fingers are movable and held extended by flat springs. When the end joint of a finger is flexed by the help of the sound hand or by pressure against some resisting object, the other joints of that finger also flex and all are locked by ratchet gear in the positions thus acquired. To release them and extend the fingers again, pressure is made on a projecting knob or button on the exterior of the hand. The whole mechanism is very ingenious and elaborate.

The remains of another sixteenth century artificial arm have been found in the tomb of an Alsatian gentleman who died in 1564. It was made apparently "for an amputation near the

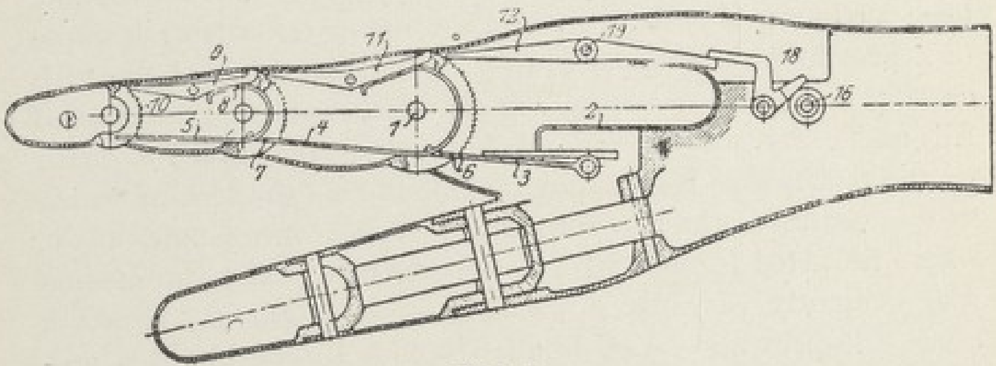


FIG. 1.

elbow-joint; an elbow-joint capable of passive movement is provided, movement at the wrist is possible, the thumb and fingers can be flexed at both the phalangeal and metacarpo-phalangeal joints. By pressing one button the thumb is extended, on another the fingers are extended" (*Lancet*, May 24, 1919).

That great French surgeon, Ambroise Paré, who, as a military surgeon, must have had to do with many amputations, describes both leg and arm prostheses in his "Dix Livres de la Chirurgie," published in 1564, and gives exact drawings of them, which, as he wrote, he had by great entreaty obtained from a locksmith in Paris, known as "Le petit Lorrain . . . with the names and explanation of each part of the said portraits, made in the technical terms of an artisan so that any locksmith or clock-maker could understand them and make similar artificial arms and legs."

The figures and descriptions here reproduced fully bear out Paré's claims. It will be noticed that in the artificial hand and arm no attempt was made to give volitional control over the movements of the joints. These could be set in certain positions and fixed there firmly, and released by the intervention of the sound hand or by pressure against some external object.

It is probable that with such an arm and hand it would be possible for a soldier to hold the bridle, leaving his sound arm free to wield a sword, as is recorded of the Huguenot Captain François de la Noue in the sixteenth century, who is supposed to have been supplied with a similar prosthesis (see note, vol. ii.,

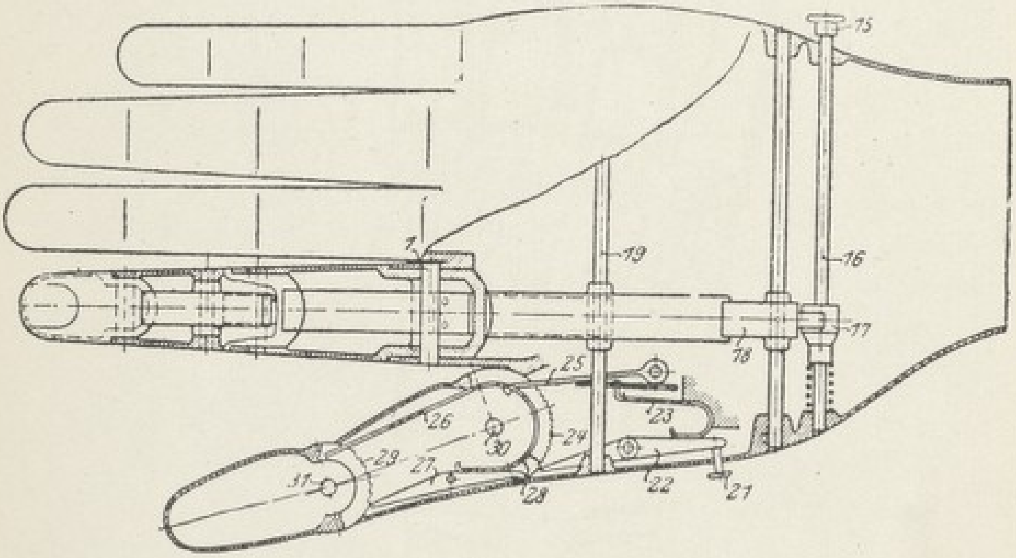


Fig. 2.

p. 617, "Œuvres Complètes d'Ambroise Paré," edited by J. F. Malgaigne, Paris, 1840). This is a more modest claim, and one more acceptable, than that made for the arm of Götz von Berlichingen (see above).

1. Pinions, each working one finger, which are of one piece with the fingers, fitted (*adjoustés*) and assembled inside the back of the hand (see fig. 3).

2. Iron pin which passes through the middle of the said pinions, on which they turn.

3. Catches to hold firm one finger each.

4. "Estoqueaux" or stops of the said catches, in the middle of which are pegs to stop the said catches.

5. The great catch which opens the four small catches, which hold the fingers closed.

6. The button of the tail of the great catch, on which if one presses, the hand will open.

7. The spring which is beneath the great catch, serving to return it to its place and holding the hand closed.

8. The springs of each finger which replace the fingers, and cause them to open themselves when they are shut.

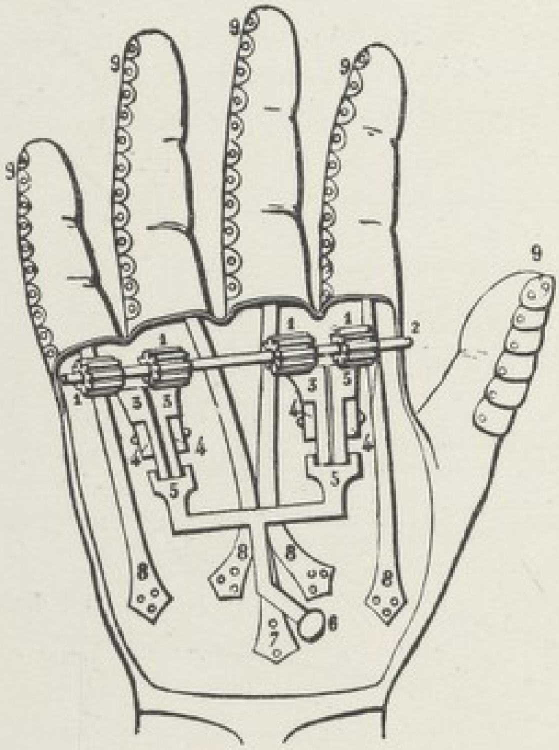


FIG. 3.

Apparently, these fingers were kept extended by flat springs, and when one or all were flexed by external pressure, they were held so by catches which engaged in pinions (cogs). They were one and all released and sprang open on pressure on a button.

On the outer side of the elbow is a special helical spring with an arbor and ratchet and flute key. On releasing the ratchet, the spring extended the elbow until the ratchet engaged again. There was apparently no stop to flexion. The socket and forearm were all of iron.

Fig. 4 shows the outside of the hand and the method of attachment of the arm to the sleeve of the doublet.

1. The forearm piece and socket (bracelet) of iron to represent the shape of the arm.

2. The arbor placed inside the large spring in order to wind it up.

3. The large spring at the elbow, which should be of tempered steel and 3 feet long or more.

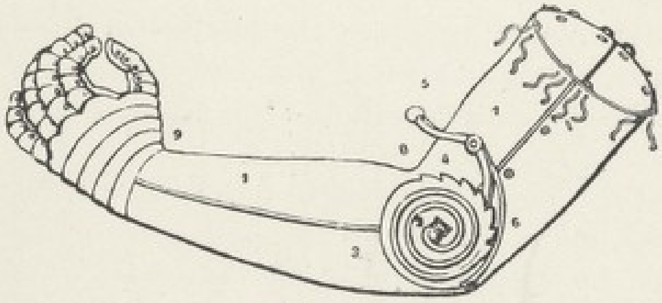


FIG. 4.

4. The ratchet.

5. The catch (or pawl).

Fig. 5 is not described by Paré. It represents a prosthesis for a forearm or wrist amputation, and no doubt the mechanism of the hand would be the same as that in the first of his illustrations.

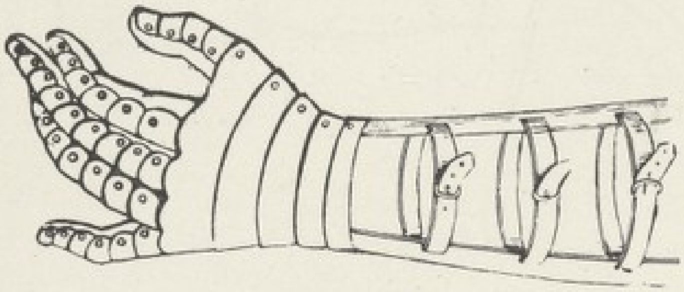


FIG. 5.

Fig. 6 was first published in 1585, and is thus described:

"Portrait of a hand made of moulded leather (*cuir bouilli*), or gummed paper (*papier collé*), the fingers holding a pen for writing, for those who have had the whole hand amputated, into which the patient puts his stump as far as possible, and which is fastened to the sleeve of the doublet by certain holes which are seen in the figure."

Probably few of the elaborate hands just described were used, and throughout the next two centuries arm prostheses consisted simply of a leather bucket and hook, fastened to the body by straps. After the Napoleonic Wars in 1818 Peter Baliff, a Berlin dentist, made a notable advance, for he appears to have been the first to introduce the use of the trunk and shoulder-girdle muscles as sources of power to flex or extend the fingers.

This method has since been very generally adopted, and is used in all, or nearly all, modern mechanical arms. As will appear later, it may be called the method of *extrinsic* as contrasted with that of *intrinsic* muscular control introduced by Vanghetti in his cinematization. The hand is shown in figs. 7 and 8.

The normal position of these fingers is in flexion. Each is of three joints, hinged on the palmar surface. Flexion is maintained by special springs, and extension through catgut

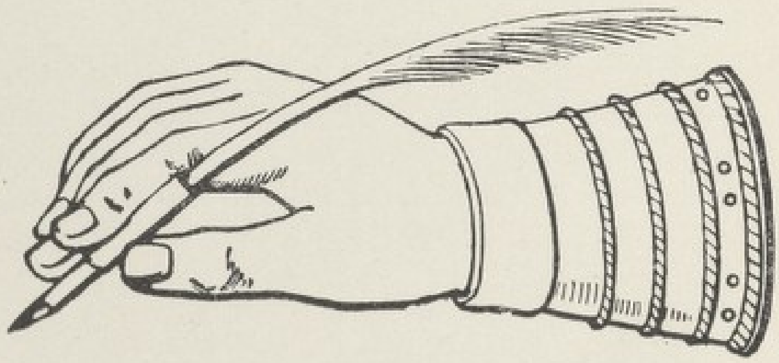


Fig. 6.

cords worked by the action of the sound shoulder, with straps round the chest. The weak point is the spring flexion of the fingers, and consequent weakness of grasp. Moreover, the grasp is only possible with the tips of the fingers and thumb, and consequently only small, light objects can be held.

It will be noted that Baliff reversed the spring action of Paré's and the "Götz" hands.

About the end of the eighteenth century, however, Klingert's artificial arm for above elbow amputations was introduced. This was a most elaborate artificial arm and hand, with spring extension of fingers. All the natural movements of the arm and forearm and wrist except ab- and adduction could be performed with this, but as there were ten catgut cords, each or all of which had to be pulled upon by the sound hand, it cannot have been of much practical value. As Schlesinger, who describes it

(" Ersatzglieder," etc., Berlin, 1919, pp. 404, 405, fig. 190), remarks, the movements desired might much better be carried out with the sound hand. This arm is mentioned here as an example of a useless prosthesis designed without any apparent sense of what is of practical value.

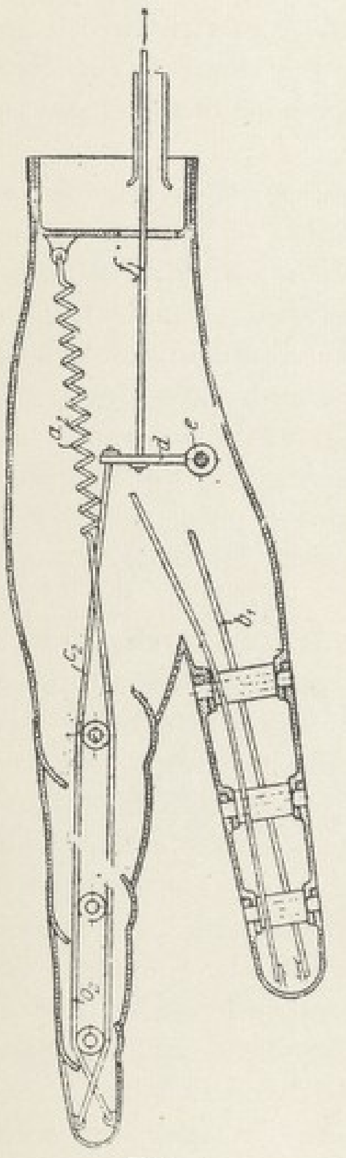


FIG. 7.

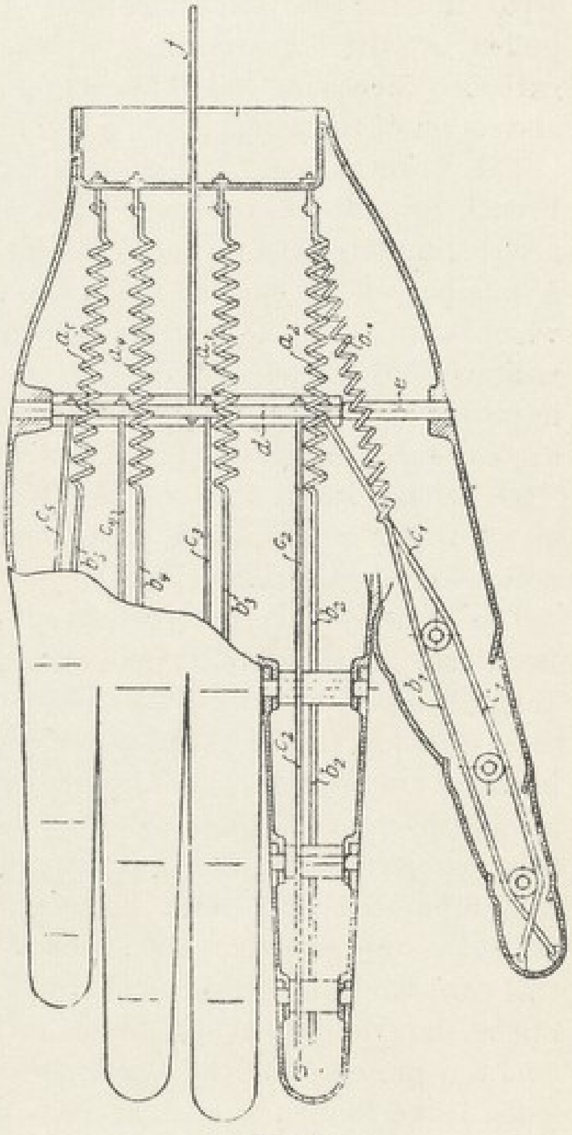


FIG. 8.

Baliff's arm was designed for a forearm amputation, for which no elbow-flexing mechanism was needed. The first arm for above-elbow amputation, in which Baliff's principle was applied to flexion of the elbow, was that invented by a Dutch sculptor, Van Peeterssen, and submitted to the Academy of Sciences in

Paris in 1844.[1] This prosthesis was reported upon favourably by Professor Magendie. A catgut cord attached at its upper end to a special corset behind the sound shoulder passed into the back of the upper arm segment of the prosthesis, over the front of a ball at the elbow, to be inserted into the back of the artificial forearm. Flexion or abduction of the stump and socket, by separating the points of attachment of the cord tightened it and pulled up the forearm into a flexed position. Other cords extended the spring-closed fingers on extension of the elbow and abduction of the arm.

The Crimean and Italian campaigns in which the second French Empire was engaged, left a number of amputees whose needs stimulated the inventive genius of the Comte de Beaufort. A number of mechancial arms were devised by him, some of which were approved by the French Government for issue to military and naval invalids. M. de Beaufort also devised an improved cheap and simple artificial leg, which was much used at one time in Italy. These are described in his pamphlet, "Recherches sur la Prothèse des Membres," published at Paris in 1867, but many of his inventions were brought to public notice some years earlier.

The annexed figures reproduced from this work show de Beaufort's methods of employing extrinsic sources of power. Judging from contemporary reports, these prostheses gave great satisfaction. Fig. 9 shows the method employed for a forearm amputation. The controlling cord, starting from a button in front of the trousers, passed through a loop which was fastened round the opposite axilla, over the shoulder of the amputated side, down the front of the arm, and round a pulley at the elbow to the artificial hand. It is evident that this cord could be pulled upon by several different movements of the shoulder and trunk, as, in fact, was done by the wearer. who was presented to the Academy of Medicine in Paris in 1860, when he performed as striking feats as any of those with which the most up-to-date arms are now credited.

Fig. 10 shows another prosthesis for forearm amputation with a simple hand with movable thumb worked in the manner now familiar in many wooden hands. The arrangement of the control cord is clearly shown.

[1] *Bulletin Général de Thérapeutique*, tome 58, p. 46. Paris, 1860.

In fig. 11 is shown the arrangement of harness for the control of a spring thumb in a case of above elbow amputation.

In this arrangement two cords start from a trouser button in front of the opposite hip. One of these passes in front of the same shoulder, round the back of the neck, and in front of the shoulder of the mutilated side, to be fixed by two divisions

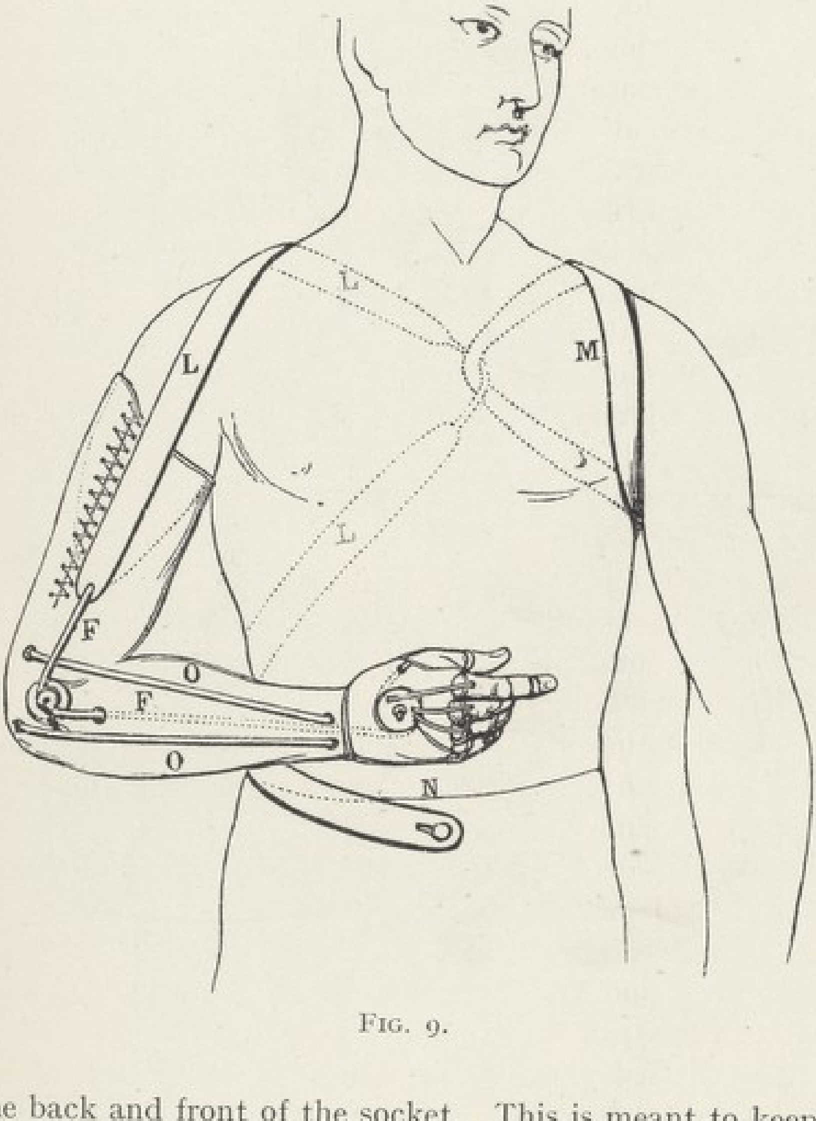


Fig. 9.

to the back and front of the socket. This is meant to keep the arm in place without hampering the shoulder. The other cord passes diagonally behind the back to the back of the shoulder of the mutilated side, where it passes through a loop or pulley on the first cord and behind the artificial elbow to the thumb. This arm has a lock at the elbow.

M. de Beaufort showed in 1855 to the Society of Surgery an above elbow prosthesis, in which the elbow was flexed by pressure of a lever against the side of the chest. This method has recently been resuscitated. He also presented to the Academy of Medicine in 1858 a hand in which opening and closing the fingers was effected by repeated pulls on the same cord. This also has been

Fig. 10.

done in more recent arms, as described later. He also introduced a locking mechanism in the thumb-joint, and shows in an illustration a double spring hook for holding objects on a principle similar to that of the well-known split hook of Durrance.

Figs. 12 and 13 show de Beaufort's mechanical hand. The fingers are kept flexed by indiarubber springs which are placed in the thickness of the hand and fixed inside the wrist at one end, and to the dorsal surfaces of the first phalanges at the other.

A is a pulley countersunk in the back of the hand.

The catgut cords BC, DC, and EC are attached to the dorsal surface of the same phalanges and to the pulley, which

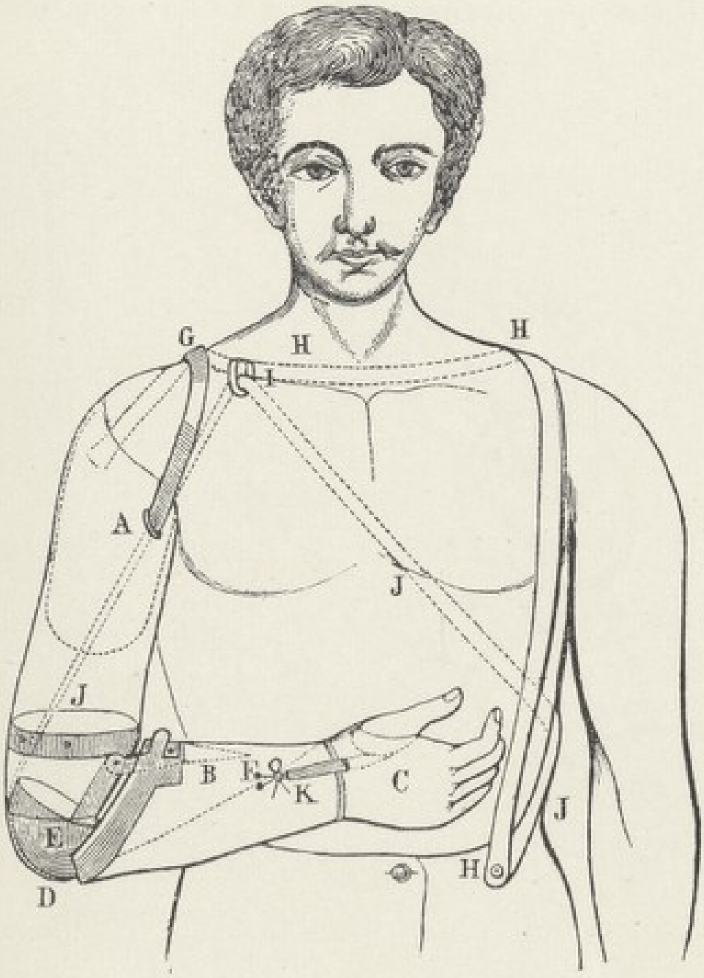


FIG. 11.

is caused to rotate by traction on the catgut cord F, which descends from the shoulder, etc. G is one of the indiarubber springs which flexes the fingers. The attachment of the cords is so arranged that, as will be seen in the figure, traction on the cord F will first act on the index finger, next upon the other fingers, and lastly on the thumb.

HI is a spring which tends to keep the finger straight; JK is a catgut cord, one end of which is fixed to the hand and the other to the end phalanx. The point I is eccentric relatively to the rotations of the finger, so that the cord flexes the distal phalanges when the proximal one is depressed.

The following remarks of de Beaufort on this and other hands are worth quoting. He writes: " Certain combinations may be made in order to vary the working of the fingers, so as to produce diverse movements of the wrist and forearm in imitation of

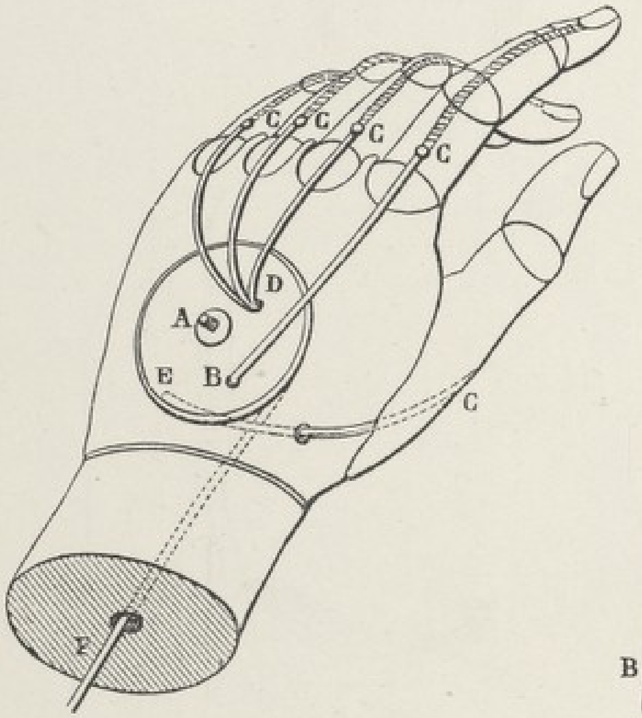


FIG. 12.

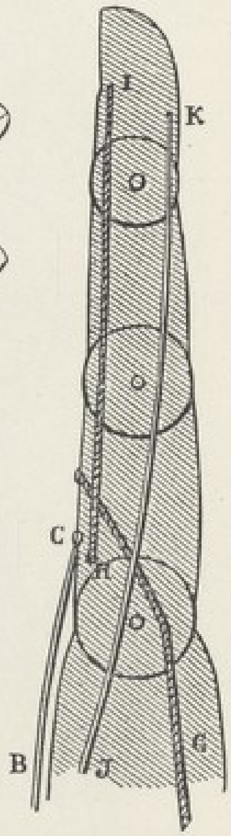


FIG. 13.

nature; but to overcome these difficulties it is necessary to use artifices which weaken the means of action and necessitate great expenditure of force."

" The marvellous, moreover, can only be attained at the price of certain sacrifices, therefore one ought not to have recourse to it except when it is indispensable, not only to hide a mutilation or a deformity, but yet more to turn aside curious glances by the variety and natural appearance of those movements which the prosthesis is capable of performing."

The cheap and simple de Beaufort legs are shown in figs. 14 and 15. These are for through-knee or thigh and for below knee amputations. The short rocker foot, about two-thirds the normal length, is the salient feature of these limbs. It is made of wood and cork covered with leather. There is no ankle-joint. Two battens jointed at each side of the knee and fixed to leather

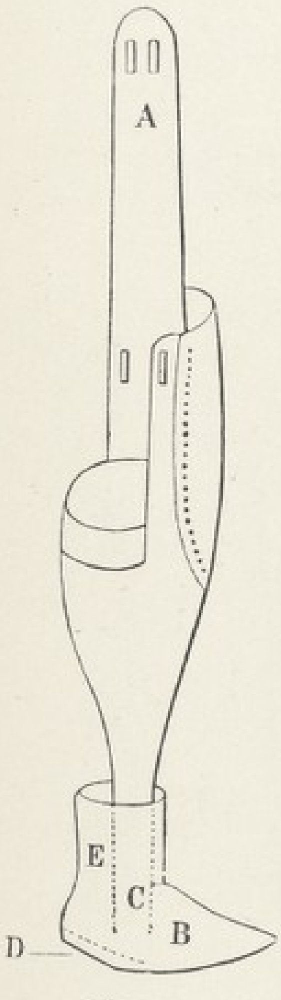


Fig. 14.

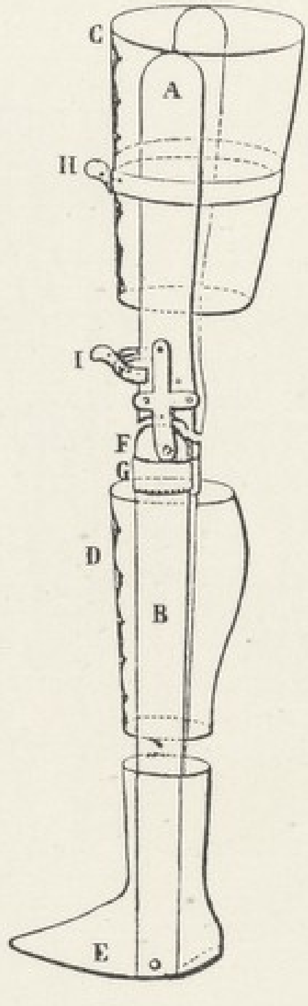


Fig. 15.

sockets form the shin and thigh parts of the limb. The knee-joints are only used for sitting down, and are locked for locomotion.

Karoline Eichler, a Berlin instrument maker well known in her day, developed Baliff's principle, but in her hand, which is shown in fig. 16, the normal position is one of extension, maintained by spiral springs. Flexion is effected by means of catgut cords worked by the sound shoulder. Thus the arrangement is the converse of Baliff's. Flexion of the elbow of the artificial arm also bends the fingers. There are locks to all the fingers. The hand is not very durable, owing to the extensive use of

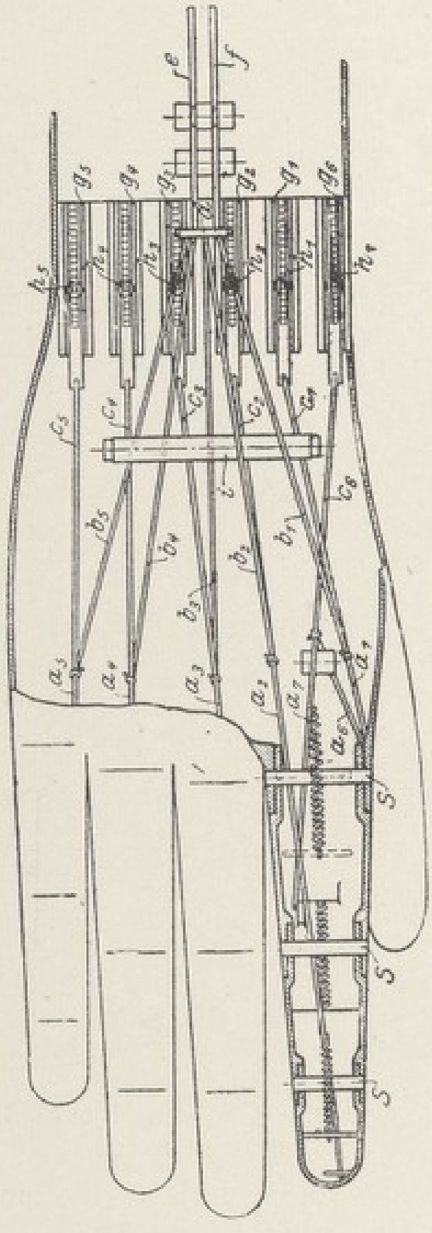


Fig. 16.

small catgut cords. In Dalisch's hand of 1872, which is shown in figs. 17 and 18, the fingers are worked by rods, which pull and push like the connecting rods of a steam engine, and effect thereby flexion and extension. The simple and rather crude hand of Clasen, produced in 1886, embodies the principle of the worm gear, which is successfully used in the Carnes arm. This gear is meant to be worked by friction of a milled wheel, which projects from the back of the hand, against

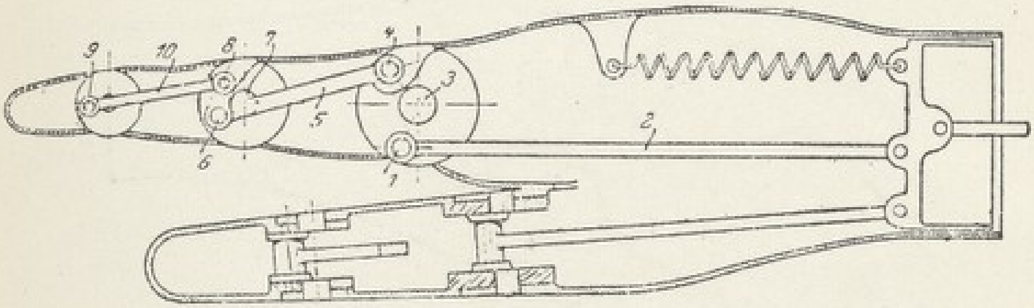


FIG. 17.

any flat surface. It may, obviously, also be worked by the sound hand. This hand shows the first attempt to obtain a really firm grasp capable of holding heavy objects. The fingers, however, are not jointed, except at the metacarpo-phalangeal joints.

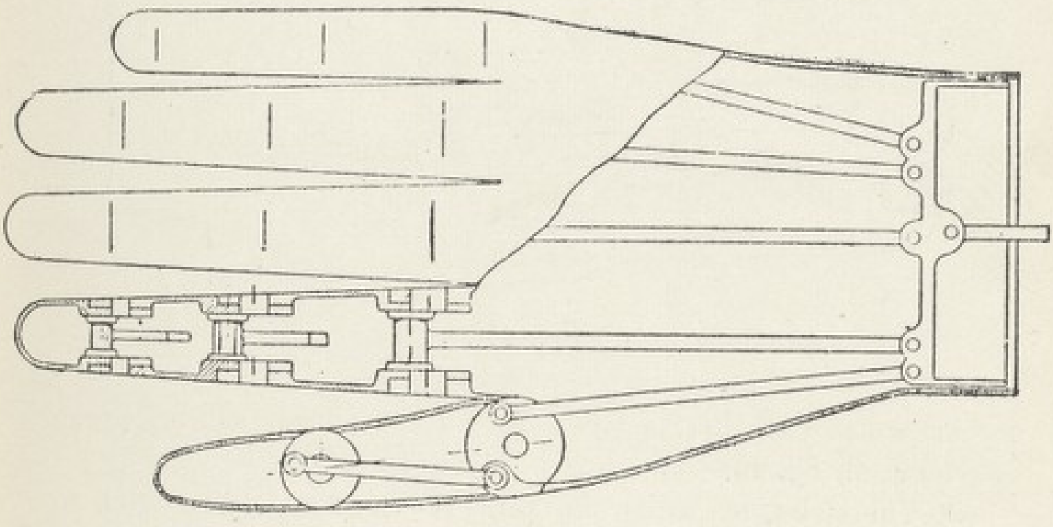


FIG. 18.

The hand of Rohrmann, of St. Gallen, which is shown in figs. 19 and 19A, has simple jointless fingers and thumb, which flex simultaneously by means of connecting levers which are actuated by a thong or cord. Extension is effected by spiral springs. The fingers can be locked in any desired position by means of a lock worked by the sound hand. Only the first and middle fingers and thumb are rigidly connected with the mechanism. The ring and little fingers are worked simultaneously, but by spring connections, which allow them to yield to pressure.

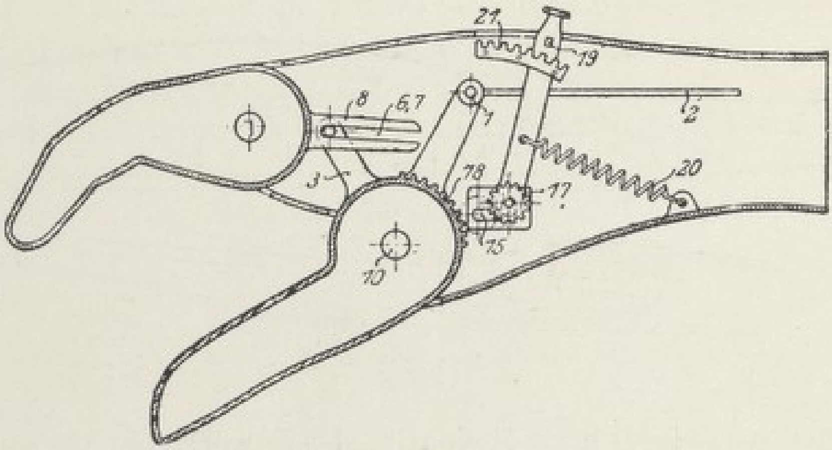


Fig. 19.

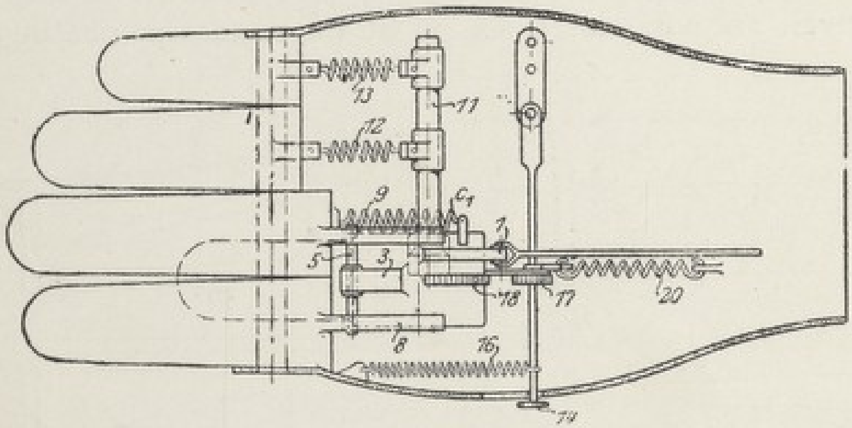


Fig. 19a.

Ambroise Paré (*loc. cit.*) describes artificial legs, one of which is shown in fig. 20.

O. The string by which one pulls on the ring of the catch to bend the leg.

1. The thigh socket, with the screws and the holes of the said screws, to enlarge or tighten on the thigh (stump) which will be inside.

2. The pummel on which to place and rest the hand and to turn oneself.

3. The little ring which is in front of the thigh, to straighten and direct the limb where one wishes.

4. The two front buckles and the one behind to hold and attach the limb to the body of the doublet.

5. The hollow below, within which the thigh (stump) is placed as far as two fingers' breadth from the end, serving also to produce the beauty and shape of the leg.

6. The spring which moves the catch which closes the leg (locks the knee).

7. The catch which holds the pin of the leg straight and firm, so that it shall not give way.

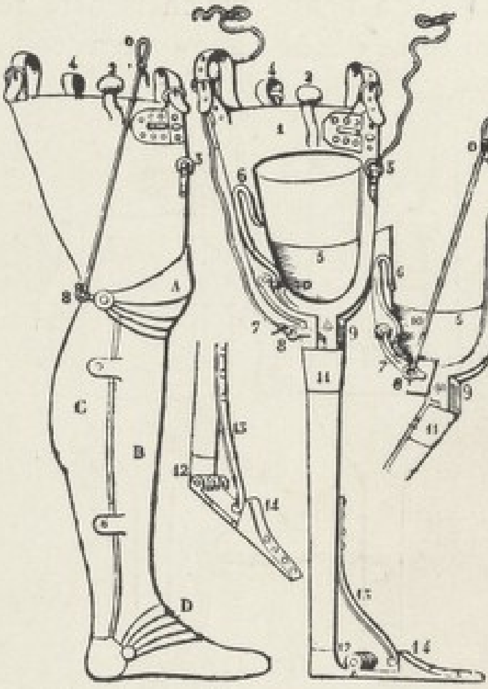


FIG. 20.

8. The ring, to which is attached a cord to pull on the catch in order that the pin may bend (at the knee) when one sits or is on horseback.

9. The hinge to allow the leg to move (at the knee), placed in front of the knee.

10. A small stop to prevent the catch from passing outside the thigh piece, for if it does so pass, the spring will break and the man will fall.

11. Iron ferrule into which the pin is inserted.

12. Another ferrule at the end of the pin.

13. A spring to make the foot return to its place.

14. The stop which serves as a spring to throw back the foot downwards.

A. Blades to form the shape of the knee.

B. Shin piece to form the shape of the leg.

C. Calf piece to complete the shape of the leg

D. Blades to form the ankle.

These blades appear to have been overlapping plates of thin metal such as were still used in armour in 1564.

The reference under "8" to riding on horseback shows that artificial limb makers in the sixteenth century claimed to make limbs as useful as their successors do in the twentieth.

Lastly, Paré shows a figure, which is here reproduced, and which will be seen to be of the same type as some peg legs even

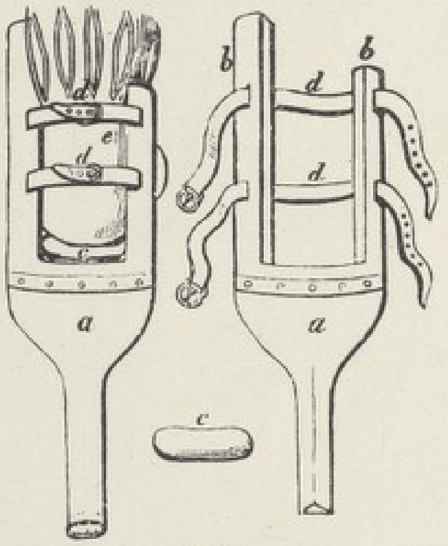


FIG. 21.

now in use, for amputations just below the knee, known as kneeling peg legs (see fig. 21).

aa. Represent the tree of the leg.

bb. The two forks into which to insert the thigh, of which the shorter is on the inner side.

cc. Shows the cushion, which is placed to support the knee comfortably on the hollow of the tree.

dd. Are the straps, with buckles traversing the forks of the thigh in two places, to squeeze it and hold it firm between them.

By *e* is marked the thigh in order to show the correct position of it on the said wooden leg.

Peg legs, attached to the body by wooden or leather sockets, have probably been made and worn since very remote times.

In "Hudibras," Samuel Butler describes Crowdero as wearing an oaken peg leg. The accuracy of the author's observation is attested by his description of the wearer's gait, in which as much as possible of the weight was placed upon the sound limb, and the wooden one was always in front of, or beside, never behind, the live one.

Veterinary prosthetics may almost be said to be non-existent, but it seems that in the seventeenth century some perhaps isolated effort was made in this direction, for the diarist John Evelyn records the successful application of a peg leg to a crane then in St. James's Park.

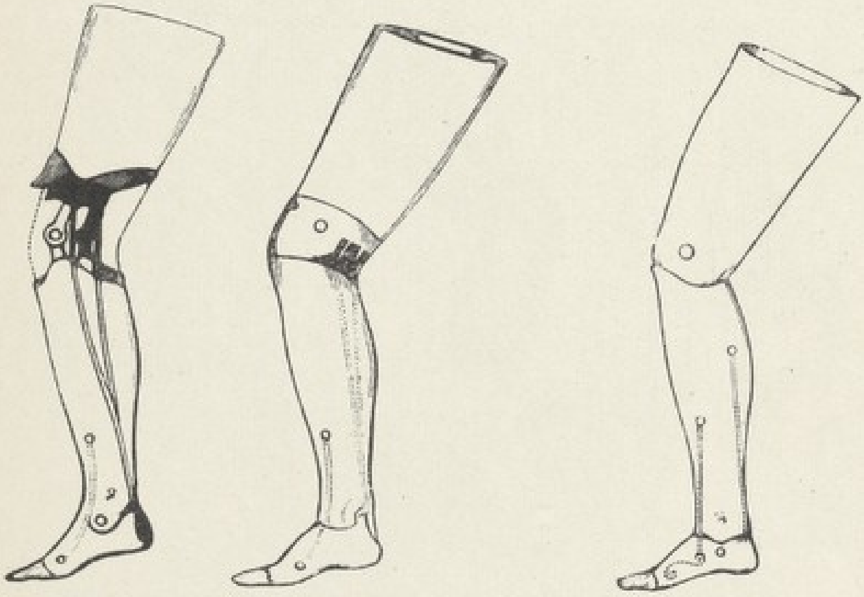


FIG. 22. FIG. 23.

For many years the "clapper leg" (so called because locomotion was apt to be accompanied by a clapping sound, due to the wooden stops in front of and behind the ankle) was generally used, but in the middle of the nineteenth century a limb maker named Potts invented the Anglesey limb, in which for both above and below knee prostheses flexion-extension of the knee and ankle joints was associated by means of tendons acting as described later in the section on gait. These legs are shown in fig. 22.

The Palmer leg had a foot made somewhat on the modern American plan, but with catgut cords and an anterior spring instead of indiarubber buffers. It is shown in fig. 23.

The leg invented by Dr. Bly of Rochester, New York, was highly spoken of by Bigg. The ball-and-socket joint at the ankle, with no metal in it, was intended to allow movements similar to those of the natural foot and ankle, want of which was supposed to cause great instability on unlevel ground and abrasion of the skin from pressure and lateral strain on the stump (figs. 24 and 25 [1]).

B. Ivory or glass ball resting on vulcanized rubber bed.
C. The cords or tendons (only three are visible).
S. Rubber springs.
N. Nuts.

Fig. 24.

The five catgut tendons around the ankle could each be adjusted by turning the nuts which secured them just below the knee.

These nuts rested upon rubber buffers, which were compressed when the tendons were tense.

"At the knee there is a mechanical arrangement representing the crucial ligaments, and affording natural action to that articulation, by which all shock to the stump in walking is avoided" (see 2, fig. 25).

Dr. Bly also introduced the curved knee steels, which are now generally used for below knee limbs.

Great improvements have been made in limbs for disarticulation at the hip-joint in recent years, but the type at present in general use in this country is only a modification of a much older limb, such as that ascribed by H. H. Bigg to Charrière of Paris. The annexed illustration (fig. 26) is copied from Bigg's "Orthopraxy," published in 1877. From the style of the drawing it might well date back to a much earlier period, but as no

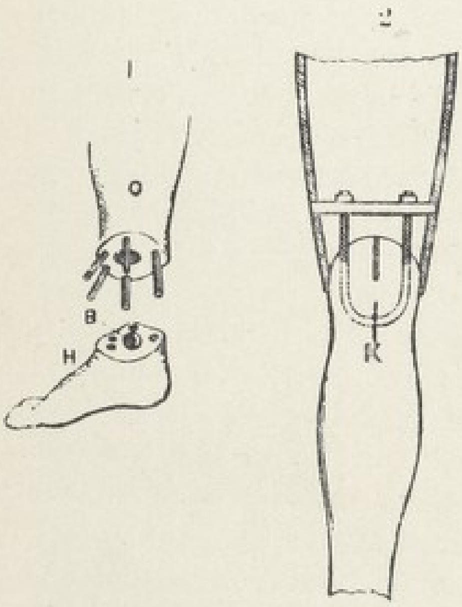


FIG. 25.

FIG. 26.

limb of this sort is described in the same author's book on artificial limbs, published in 1855, it is probable that Charrière's limb originated between these dates. It will be noticed that the hip socket extended upwards into a laced corset or waistcoat which embraced the thorax, while the modern type extends no higher than the crest of the ilium.

In Hoffa's "Orthopædic Surgery" (first edition), published in 1891, there is a drawing of a limb for hip disarticulation which is essentially the same as those which are now in general use.

CHAPTER II

AMPUTATION STUMPS

AMPUTATIONS both in civil and military practice, equally on account of disease and injury, have to be performed to save the patient's life or, at least, to cut short an exhausting disease or to rid the body of a useless segment.

These are the primary objects of amputations. The secondary object of an amputation is to provide a stump most useful and suitable for the attachment and use of a prosthetic appliance. The term prosthesis (πρόσθεσις, meaning an addition) is a convenient one, as it includes all kinds of artificial substitutes for lost parts. (The word is also used in grammar for the addition of a syllable at the beginning of a word.) On the Continent the adjective "prosthetic" is wrongly spelt without the *s*. In the following pages, for the sake of brevity, instead of using such terms as "artificial arm or leg," the word "prosthesis" will be used whenever possible. With the secondary object only are we concerned in the present work, and therefore amputation stumps will only be discussed in so far as their fitness to bear artificial substitutes is concerned.

For a good many years before August, 1914, amputations of the limbs had become a comparatively rare operation in this country; for instance, as Mr. Edred M. Corner has kindly informed me, at St. Thomas's Hospital, London, out of 5,483 major operations performed in 1913, there were only 34 amputations. In 1915 the Royal Surgical Aid Society had supplied 384 legs and arms among a total of 39,290 appliances. Not only were these operations comparatively rare in this country, but they were generally regarded as uninteresting, and little consideration was given to the subject by teachers. The war has drawn attention again to the importance of amputations, and the experience gained in the treatment of some 40,000 amputees, the victims of enemy action, has caused a revision of some of the opinions which were accepted formerly.

In the United States of America it would appear that amputation was a much commoner operation, not because of any lack of conservative surgery, but because accidents are relatively and positively much commoner in that country. The large number of cases of amputation among the survivors of the War of Secession gave an impetus to the manufacture of artificial limbs, which was sustained by the heavy demand caused by accidents in civil life, and made the rewards of ingenuity in the design and construction of prostheses larger and more certain than in this country.

The following statistics relating to the number of officers, non-commissioned officers and men who have lost limbs in the Great War have been kindly furnished by the Director-General of Medical Services of the Ministry of Pensions. It is understood that these numbers do not include members of the Overseas Forces for whom the Ministry was not responsible.

In round figures the total amounts to 41,300, which is thus made up:

Lower extremity	29,950 (72·5 per cent.)
Upper extremity	11,350 (27·5 per cent.)
Total	41,300

No information is available regarding the sites of arm amputations.

It is not surprising that in the difficult conditions of the wide-spread and scattered theatres of war, and under the enormous pressure caused by the unprecedented number of wounded, exact details could not be universally recorded. In order to obtain some idea of the exact sites of amputations in the upper as well as the lower extremity, the records of 1,000 cases treated at Queen Mary's Hospital, Roehampton, were examined. As about half the amputations which have been fitted with limbs in this country passed through this hospital, a fairly representative result may be hoped for from this number of cases, taken indiscriminately, omitting those of which exact measurements were not recorded.

Of these 1,000 cases 30 were cases of loss of two limbs, making 1,030 amputations.

There were 723 of the lower and 307 of the upper extremity.

Putting the double amputations in a separate category, there were—

Double amputations	30	(3 per cent.)
Upper extremity	297	(29·7 ,,)
Lower extremity	673	(67·3 ,,)
Total	1,000	

Of the double amputations there were—

Of both arms	1 case.
Of one upper and one lower	4 cases.
Of both thighs	5 ,,
Of both legs	8 ,,
Of one leg and one foot (Syme's)	1 case.
Of both feet (Syme's)	1 ,,
Of one thigh and one leg	10 cases.
Total	30 cases.

Among some 24,000 cases treated at Roehampton, nearly every combination of mutilations has been met with, of which the more rare would not be likely to occur in every thousand cases. Thus some, such as disarticulation of both shoulder-joints, loss of three limbs, and so forth, are not mentioned in the above statistics.

The amputations of the upper extremity (including double amputations) are thus classified:

Fore-quarter	1
Shoulder	29
Elbow	7
Wrist	19
Upper arm	175
Forearm	75
Hand	1
Total	307

The amputations of the lower extremity (including double amputations) are thus classified:

Hip-joint	11
Knee ,,	14
Thigh	441
Leg	219
Syme's	32
Chopart's	4
Pirogoff's	2
Total	723

Except for a distinct but small preponderance of the left thigh and leg over the right, the two sides are equally liable to amputation. The sites of amputation in the upper arm, forearm, thigh, and leg, respectively, were as follows:

Length of Stump of Bone.	*Upper Arm.*	*Forearm.*	*Thigh.*	*Leg.*
0 to 1 inch	0	1	0	0
Over 1 and up to 2 inches ..	5	1	1	3
,, 2 ,, ,, 3 ,, ..	2	6	2	12
,, 3 ,, ,, 4 ,, ..	10	10	4	36
,, 4 ,, ,, 5 ,, ..	22	12	9	36
,, 5 ,, ,, 6 ,, ..	18	11	17	27
,, 6 ,, ,, 7 ,, ..	24	10	36	22
,, 7 ,, ,, 8 ,, ..	41	12	40	27
,, 8 ,, ,, 9 ,, ..	15	5	42	25
,, 9 ,, ,, 10 ,, ..	21	5	46	12
,, 10 ,, ,, 11 ,, ..	8	2	52	11
,, 11 ,, ,, 12 ,, ..	8	—	57	6
,, 12 ,, ,, 13 ,, ..	1	—	48	2
,, 13 ,, ,, 14 ,, ..	—	—	40	—
,, 14 ,, ,, 15 ,, ..	—	—	18	—
,, 15 ,, ,, 16 ,, ..	—	—	18	—
,, 16 ,, ,, 17 ,, ..	—	—	9	—
,, 17 ,, ,, 18 ,, ..	—	—	1	—
,, 18 ,, ,, 19 ,, ..	—	—	1	—
Total	175	75	441	219

Until about three years ago the official classification of stumps, as regards their length, was based upon a scale of thirds, and pensions were awarded, other things being equal, according to whether the line of section was in the upper, middle, or lower third. No method of measurement was laid down, and a rough estimate by the eye was all that there was to go by. After the author had had to deal with some hundreds of cases, it became evident that he, in common with other surgeons, had made many erroneous estimates, and a system of exact measurement from such bony points as were palpable was adopted and afterwards made official by the Ministry of Pensions. In order to compare measurements taken in inches or centimetres with thirds of a limb, measurements *in vivo* of 100 patients were taken at Roehampton at the author's request by Surgeon A. C. McAllister, R.N. The results, which may be of some statistical interest, are here given in full. It is to be noted that these measurements include the soft parts covering the bones, which soft parts vary in thickness in different situations in the same person and in different persons in the same situation. They cannot, therefore, be compared with exact museum measurements taken from the dry bones, or from recent dissections.

Number of Cases at each Height.			Average Length of Bones at Each Height.			
			Femur.	*Tibia.*	*Humerus.*	*Ulna.*
Feet.	*Inches.*					
5	2	1	17·5	13·5	10·5	10·25
5	3	9	17·6	14·6	11·9	10·02
5	4	15	17·6	14·4	12·25	10·36
5	5	15	17·5	14·7	11·9	10·36
5	6	16	17·95	15·5	12·4	10·5
5	7	14	18·2	15·4	12·5	10·6
5	8	10	18·7	15·75	12·87	10·8
5	9	15	19·4	15·4	12·9	10·9
5	11	1	19·0	15·5	13·25	11·0
6	0	3	20·6	17·5	12·12	11·9
6	2	1	21·0	20·0	15·0	12·5

The total height of all 100 cases was 553 feet, giving an average height of 5 feet 6 inches.

Thus the average lengths of the bones are as follows:

From 100 Cases.	*Inches.*	*At 5 Feet 6 Inches, as per Table Above.*	*Inches.*
Femur	18·6	Femur	17·95
Tibia	15·6	Tibia	15·5
Humerus	12·49	Humerus	12·4
Ulna	10·8	Ulna	10·5

The heights of 85 per cent. of these men were from 5 feet 4 inches to 5 feet 9 inches (inclusive). There were more men of the height of 5 feet 6 inches than of any one other height. The following table shows the average difference of length of the femur and tibia added together between the six commonest heights:

	Heights.					
	5′ 4″	5′ 5″	5′ 6″	5′ 7″	5′ 8″	5′ 9″
Femur	17·6	17·5	17·95	18·2	18·7	19·4
Tibia	14·4	14·7	15·05	15·4	15·75	15·4
Total	31·10	31·12	33·0	33·6	34·45	34·8
Difference ..	—	0·02	1·88	0·6	0·85	0·35

Measurements of total height were taken with the usual standard. The other measurements were taken between parallels with a shoemaker's size-stick, which was made in the educational workshop at Roehampton with a longer scale than usual—namely, one of 22 inches (see fig. 27).

The data, or points of measurement, are as follows:

The upper ones, at the shoulder: The tip of the acromion process, when the stump hangs down by the side. In practice it is found more convenient to make the patient hyperextend the arm or stump, so that the head of the humerus is exposed beneath the skin in front of the joint, and to place one blade of the measure on the top of the bone (see fig. 27). This method gives the same results as measurements taken from the acromion.

At the elbow: The back of the olecranon, the forearm or stump being flexed to a right angle (see fig. 28).

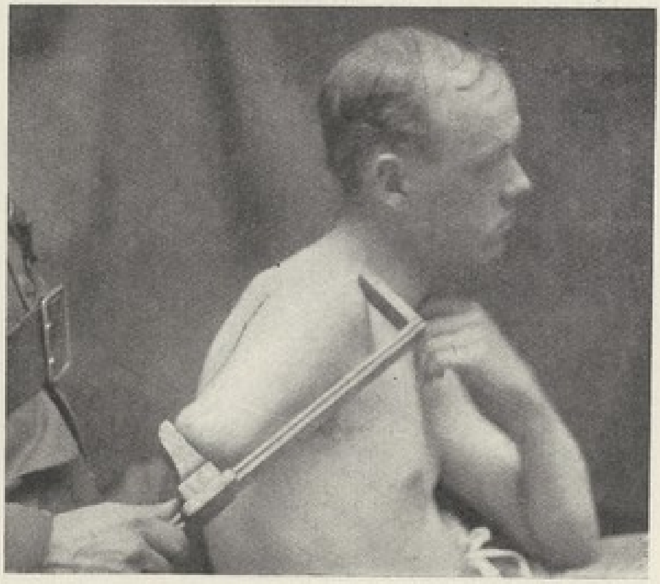


FIG. 27.

At the hip: The tip of the great trochanter. In very fat or muscular men it may be difficult to make this point out. With the patient lying supine, and the thigh or stump supported by an assistant, so as to relax the muscles, this point can, however, always be defined (see fig. 29).

At the knee: The anterior edge of the upper articular surface of the tibia, preferably its inner part. With the knee bent, and the leg or stump supported so as to relax the quadriceps, this can always be felt distinctly (see fig. 30). The lower surfaces are in all stumps the end of the bone as felt beneath the skin when any redundant soft parts are held aside.

In measuring the sound limbs the lower points of measurement are—

For the humerus: The lowest palpable part of the external condyle.

Ulna (for the forearm): The tip of the styloid process.

Femur: The distal articular surface of the outer condyle, easily palpable when the knee is flexed.

Tibia: The tip of the inner malleolus.

FIG. 28.

As in many cases the amount of pension depends upon the exact length of the patient's stump, accurate measurement is necessary when dealing with the numerous pensioners who have suffered amputation.

An ideal amputation stump would be as long as possible, so as to get the maximum leverage and to secure control over the prosthesis. Its covering would consist of healthy soft parts, with plenty of subcutaneous tissue; the scar would be a linear one not adherent to the bone, and so situated that it would not be exposed to undue pressure by the prosthesis.

It would have attached to it such muscles as would suffice to move it with adequate force. No unduly sensitive nerve ends would be palpable in it. The bone would be healthy, and its extremity of such a form as not to inflict injury or cause pain when pressure took place between it and the surrounding soft parts.

Amputation through a joint would seem at first sight most nearly to realize this ideal, as it provides the greatest possible length and does not necessitate any interference with the structure of the bone. On the Continent, and particularly in Germany, disarticulations are much in favour, but British surgeons and makers of artificial limbs are agreed in the conclusion that, except

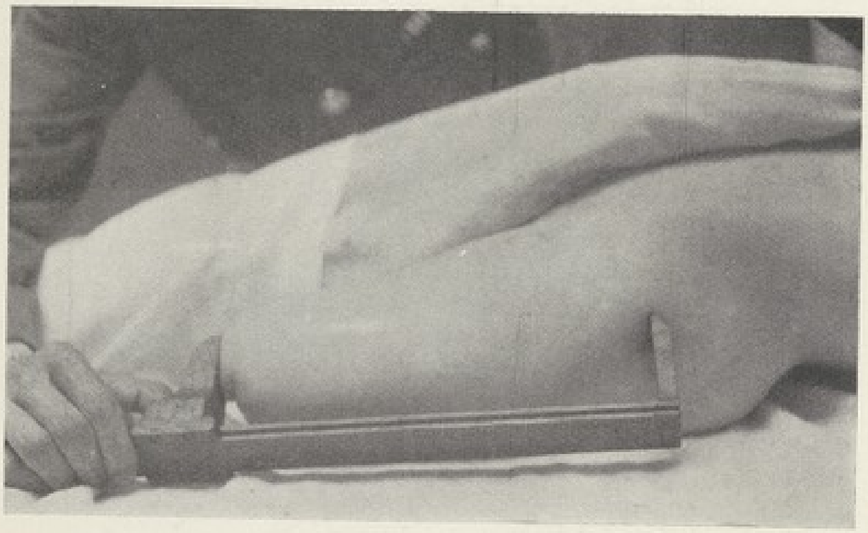


FIG. 29.

in the case of the hip and shoulder, where there is no choice, disarticulations do not provide satisfactory stumps for the following reasons:

1. The articular end of the bone is always more bulky than the shaft; consequently, the resulting stump is always more or less bulbous immediately after the operation, and becomes still more so as time goes on, and the soft parts shrink. It is very difficult, if not impossible, to fit such a stump properly with a rigid socket, such as is generally to be preferred. Another objection is that the artificial limb must be wider than the natural one at the end of the stump, and consequently unsightly.

2. The joint of the artificial limb cannot be fitted on a corresponding level to the sound limb unless it is placed on the sides of the end of the stump, making the artificial limb still wider than its fellow and increasing its asymmetry.

3. Large flaps are needed to cover the bone end, and these are often difficult to obtain in such a situation, and are likely to be of low vitality and prone to slough.

If any exception might be made to the foregoing generalization, it would be in the case of disarticulation at the knee-joint, but even here it is not often found that a true disarticulation gives a good end bearing stump, although amputation through the condyles more often does so. The advantages of a good weight-bearing stump outweigh the disadvantages in this amputation, but if that advantage is not secured, the result is inferior to that

Fig. 30.

to be looked for after amputation at a higher level. Stumps capable of bearing some part at least of the weight of the body can be produced without osteoplastic procedures. Although opinion in Germany is divided on this point, Seidler of Vienna stated at the extraordinary meeting of the German Orthopædic Society in February, 1916 (*Zeitschrift für Orthopädische Chirurgie*, Band xxxvi., Heft 2-3), that out of 500 stumps he had found 297, or nearly three-fifths, were fit to bear weight. Experience at Roehampton tallies with Seidler's, for out of 549 of the cases which in 1917 were fitted with legs, 275, or almost exactly half, were fitted with an end bearing pad.

The following table gives the proportion in the various regions of the body:

	Cases fitted with End Bearing Pad.
Upper third of thigh	1 out of 22, *i.e.*, 9 per cent.
Middle third of thigh	75 ,, 235 ,, 32 ,,
Lower third of thigh	63 ,, 81 ,, 77 ,,
Through or close above the knee-joint ..	5 ,, 6 ,, 83 ,,
Upper third of leg	42 ,, 74 ,, 56 ,,
Middle third of leg	64 ,, 98 ,, 65 ,,
Lower third of leg	6 ,, 14 ,, 43 ,,
Syme's amputation	12 ,, 14 ,, 86 ,,

Whenever there was a doubt as to the suitability of a stump to bear pressure on its end, an end bearing sling and pad was ordered. Only extended trial in each case could decide the question, and the sling and pad were inexpensive, and easily removed by the patient himself if experience proved them to be useless. As anticipated, a certain proportion of these patients discarded the pads. In 220 consecutive cases which had been originally fitted with end bearings and which returned for repairs or the supply of duplicates, this question was enquired into. It was found that 160, or nearly 73 per cent., of them were using it. The remainder had discarded it, generally because they were more comfortable without it. The details are as follows:

Supplied with End Bearing.		*Using End Bearing.*	*Percentage using it.*
Amputation above knee	124	84	67·7
Amputation through knee	8	8	100·0
Amputation below knee	88	68	77·2

From this it must not be assumed that every case of amputation through the knee-joint was fit for end bearing. It simply means that in the eight cases quoted our prognosis was correct. Amputations through the knee-joint, in which no part of the lower surface of the condyles has been removed, seldom bear pressure well. As end bearings were ordered in 50 per cent. of cases, and it appeared that, of those ordered, 73 per cent. found them advantageous, it may be assumed that in military practice about 36 per cent. of cases are suitable.

It must be remembered that these cases were nearly all originally septic, and that many had stumps with end scars adherent to bone, or otherwise unsuitable. In dealing with the results of aseptic operations, and in civil practice, a very much larger proportion of cases may be expected to be fit to use end bearings.

This question has been discussed at some length because some distinguished surgeons have given it as their opinion that no artificial leg should be so made as to press upon the end of a stump except in cases of Syme's amputation.

A priori it would seem advisable to distribute pressure as widely as possible, and as every pound of weight borne by the stump end means a pound the less pressure on other parts, end bearing is to be recommended. Extended experience in limb fitting hospitals has justified the assumption. No doubt the best end bearing stumps are those in which the section has been made through cancellous bone, but the fact that the section is through the compact bone and medullary cavity of the diaphysis has proved no bar to the use of an end bearing pad. Of course, scars over the end of the bone are not well adapted to bear pressure, although many of them may do so.

In a memorandum on amputations and amputation stumps issued by the War Office in March, 1916, the following requirements were set down as being characteristic of a good stump:

1. A good covering for the bone.
2. Sound healing.
3. Consolidation.
4. Painlessness.
5. Freedom of movement.

And the following conditions were cited as those which prevent or most commonly delay the fitting of prostheses:

1. Sinus.
2. Painful nerves or tenderness due to inflammation of the bone.
3. Unsound scars.
4. Contracture in the neighbourhood of the joint immediately above the amputation.

A good covering for the bone should consist of healthy skin and subcutaneous tissue and fascia, with the scar of union well out of the way of pressure by the socket. The skin should be freely movable. The bone should not be covered at the end with muscle, which is of no use in such a situation, may be tender to pressure, and will ultimately atrophy. Muscles and tendons should be prevented from retracting by fixation to the periosteum, but not brought over the end of the bone. There may be too much mobility of the soft parts. This occurs when, instead of fixing muscular aponeuroses to the bone end, the surgeon has sutured the flexor and extensor masses of muscles to each other across the end of the bone, and healing has taken place without adhesion between these aponeuroses and the bone. In such a case if the patient attempts to move the stump, the first effect is movement of the scar to and fro across the end. When a limb is fitted and walking is attempted, a good deal of power is wasted in this movement, and friction between the skin and the limb socket is liable to produce abrasions, etc. (see figs. 31 and 31A). Sound healing and consolidation imply that all inflammatory processes are at an end and that there is no œdema, and that the scar has reached a permanent condition as regards vascularity. Even after the wound has run an aseptic course this permanent condition may not be reached for three months. After sepsis and prolonged suppuration it may be many months before things have settled down enough to allow of the use of a permanent prosthesis.

Among adverse conditions, sinus is due to necrosis and the presence of a sequestrum of bone, or the inclusion of foreign bodies such as missiles or fragments of missiles and unabsorbed ligatures and sutures such as silk. Small sequestra and buried silk ligatures and sutures were a very frequent cause of sinus and delay in complete healing. The former cause was unavoidable, probably, in the conditions which prevailed in the late war. The latter was avoidable, and it is to be hoped will be avoided in the future. The use of unabsorbable ligatures and sutures, which are buried in the tissues, has nothing to commend it except convenience in sterilization.

An occasional cause of sinus after amputations through or near above the knee-joint is the presence of some part of the synovial membrane of the joint which has escaped removal at the time of operation. Some part of the pouch, which extends up the front of the thigh under the quadriceps, is the most likely to be left behind. This may cause a troublesome swelling, which, if it becomes infected, may suppurate and discharge, leaving a chronic sinus. It has been known first to give trouble years after the amputation was performed, but is more likely to do so earlier.

Pain in amputation stumps often continues after the skin wound has soundly healed, but in most cases such pains subside after a few weeks or months.

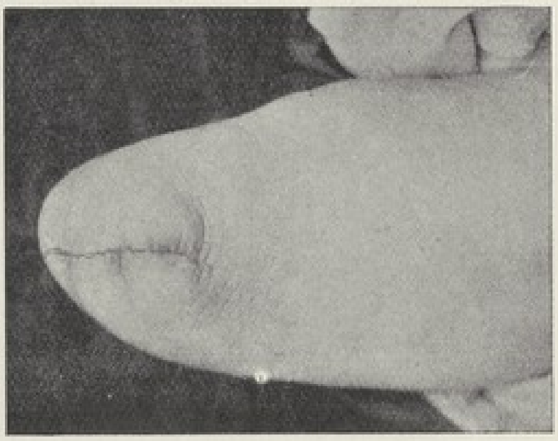


Fig. 31.—From a Photograph of a Thigh Stump taken during Contraction of the Extensor Muscles.

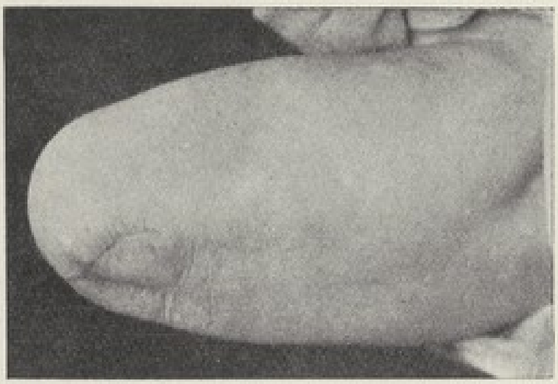


Fig. 31a.—From the Same Stump as the Preceding, taken during Contraction of the Flexor Muscles. Note the Position of the Scar in this and the Preceding Figure.

A distressing symptom in cases of amputations through the thigh, especially when the site is above the middle, is pain referred to the stump during the act of micturition, defæcation, and seminal emission. These pains may be very severe. This symptom commonly disappears spontaneously after three months or so, but it may continue for years. I have recently seen a patient who still suffers from it more than four years after the amputation was performed.

The existence of this symptom appears to be unknown to many surgeons who have to deal with amputees. Patients seldom volunteer information about it, but enquiry will soon bring forward abundant proof of its existence.

It is evidence of the profound disturbance of the spinal nervous system caused by amputation, and no doubt aggravated by sepsis, and it implies a neuritis spreading up the nerve trunks of the limb to the lumbar enlargement of the spinal cord. The treatment is the same as that of painful nerves and neuritis in the stump, which latter trouble may be kept up by the irritation of adherent scar tissue around the termination of the surviving fibres of the nerves.

Persistent pain in the stump may be due to lingering chronic inflammation, especially when affecting the bone. It is most often due, however, to the presence of painful nerve endings, which are often palpable beneath the skin as bulbous nerves. The formation of a bulb is part of the normal process of healing of the proximal end of a resected nerve trunk, and it is not necessarily painfully sensitive to pressure. Sepsis is probably responsible for the frequency of tender nerve bulbs after septic wounds. They are perhaps commoner and more troublesome in the upper than the lower extremity. The pain experienced upon pressure is sometimes only local, but most often it is also referred to the peripheral distribution of the afferent fibres of the nerve concerned. When the end of the nerve is involved in dense scar tissue, as sometimes happens, no bulb may be felt. These nerve pains generally cease as soon as pressure on the nerve ceases, but in case of active neuritis pain may be constant without any external irritation. A discussion of the micro-pathology of painful nerve endings would be out of place here; their treatment, however, is a subject of great importance to the prosthetic surgeon.

Every painful nerve end should be sought for and removed, and in addition to this the trunk of the nerve should be resected as high up as is consistent with the innervation of the muscles required to actuate the stump. Thus, in the case of an amputation between the knee and ankle, having a bulbous end to the posterior tibial nerve, the bulb should be excised and also an inch or two of the internal popliteal nerve should be resected in the thigh. The resulting paralysis of the inner head of the gastrocnemius is of no consequence, as this muscle is not required to act on the stump, and its atrophy is often an advantage.

It is not enough simply to resect the nerve, as a new painful bulb may then be formed. It is advisable to crush the nerve trunk at the site selected for division with a smooth-jawed appendix clamp, to transfix the sheath at the same site with a round-bodied needle armed with catgut (which in the case of a large nerve trunk should be stout), to tie firmly in one or two parts, and finally to inject enough absolute alcohol to distend the sheath above the ligature. When operating upon the great sciatic nerve, each half should be injected separately, as the separate sheaths of the two popliteal nerves extend for a long way up the main trunk. The object aimed at in crushing the nerve is the retraction of the axis cylinders, so that the sheath may be ligatured below their ends and their subsequent outgrowth be prevented. As it is always doubtful if this end has been completely attained, the subsequent injection of alcohol is designed to make assurance doubly sure, and to prevent pain immediately after operation. Operations have been devised and described of which the object is to seal the end of the nerve by dissecting up a sleeve of sheath before division, and afterwards suturing it closely, or to attain the same end by other means. These are difficult of performance and of doubtful efficacy. The procedures above described have given good results, and are simple and easy to carry out.

The nerves which most often require resection are the tibials and popliteals, the great sciatic, the internal saphenous in the thigh; and the median, ulnar and musculo-spiral in the upper extremity. All the main trunks of the brachial plexus, except the circumflex (which should be carefully avoided on account of its innervation of the deltoid), may require division just below the axilla. In cases of causalgia it may be advisable, as pointed out by Mr. E. M. Corner, to excise the occluded end of the main artery and its sheath, including (in the case of Hunter's canal) the internal saphenous nerve. Care should be taken to leave some cutaneous nerve supply to the skin of the stump. A stump deprived of all afferent nerve supply is likely to be damaged without the knowledge at the time of the patient, as has been seen in several cases. Trophic changes are also to be feared, although the author is not aware that any such have been reported.

There are, unfortunately, cases in which, despite repeated neurectomies, pain persists; in some only when a prosthesis is worn, and in others constantly. These most distressing cases are due probably to neuritis and to involvement of the posterior nerve roots, or even of more central parts of the nervous system. For some of these, posterior rhizotomy has been performed in vain. Associated with these cases are those of jactitating stumps, in which on pressure, or even on a light touch, the muscles moving the stump are thrown into violent clonic spasm. Reamputation has been necessary in some of these, after treatment by complete rest—such, for instance, as fixation of the joint for months in a gypsum splint—has failed. Prolonged rest and avoidance of all irritation do sometimes effect a cure, and are always worth trial before more drastic procedures are undertaken. As in some of these cases there is a strong mental element, the patients should be encouraged to occupy their minds and hands (or hand in the case of a one-armed man) as fully as possible in order to divert their thoughts from their troubles.

In septic war practice, some stumps which may have been healed for many months, and which to all appearance are quite sound with good scars and well-covered bone, on wearing a prosthesis, without any known trauma, become œdematous, hot, painful, and erythematous. In some cases an abscess results; in others, with rest and care, the inflammation subsides. It appears probable that in these cases some microbes which were safely encysted have been set free by the disturbance of the parts and have originated a fresh infection. Septic intoxication with a considerable rise of temperature may occur.

In many stumps after amputation in the field, owing to the widely prevalent sepsis, primary union of flaps has failed, or on account of gas gangrene or other acute infection no flaps have been made. In such cases, when at length healing is complete, there is bound to be a large amount of scar tissue at the end of the stump, generally adherent to the bone.

Many such stumps, although unfit to bear any weight on their ends, are yet quite suitable for prostheses, and unless the amputation is in the lower half of the leg below the knee, the advantage of length of lever outweighs the disadvantage of the bad scar, and reamputation is to be avoided. But in some cases the nutrition of the scar is so imperfect that it is unable to bear the interference with the circulation caused by the pressure of the socket of the prosthesis, or the drag on the soft parts from the same cause. If such a stump be held in the hands and the skin steadily drawn upwards, the scar will be seen to become blanched. In that case ulceration is very likely to occur when a socket is worn, as happened in the case shown in fig. 32.

Should this happen, either reamputation or some operation designed to replace the scar with healthy tissue is indicated.

As already remarked, reamputation is to be avoided in most cases. There remains, therefore, the operation of excision of scar. If despite the adherent scar there is plenty of available skin, as in the bifid stump represented in fig. 32A, all the scar tissue can be at once excised and the skin brought together on the end of the bone. To prevent the formation of new adhesions between the scar and the bone, the deeper parts of the flaps may be drawn together with buried catgut stitches, or temporary button sutures may be used in addition to those on the edges of the skin, the object aimed at being the eversion of the scar.

When there is not enough skin to provide proper covering, a preliminary course of extension should be undertaken. For this either Thomas's splint is used, or if the patient is confined to bed, weight extension may be substituted. Two stirrups of strapping are applied to the skin of the stump, one sagittally and the other transversely, so that they cross one another at right angles. Several circular strips cover and fix the ends of the stirrups on the stump. The extension cord is to be fastened to a wooden stretcher inside the stirrups, which prevents lateral pressure on the end of the stump. Weight extension is applied in the usual way, and should be as powerful as is tolerable, up to and even over 10 pounds.

When a Thomas's splint is used, an elastic accumulator or a spiral steel spring is attached to the stirrup and to the bottom of the splint by a cord, the tension on which can be regulated. In the case of the upper extremity, or in the lower if the splint is made with a patten, this treatment may be ambulatory, which is, of course, much more agreeable to the patient, and better for his general health. In treating thus forearm stumps, a difficulty is found in getting a satisfactory surface of counter-pressure. This may be overcome by suspending the stump from a collar or cravat, thus using the weight of the limb itself as the extending force.

After some weeks' steady and unremitting traction the skin will probably be stretched enough to allow of operation as already described, although sometimes it may be necessary to sacrifice a small amount of bone. When the amputation is below the

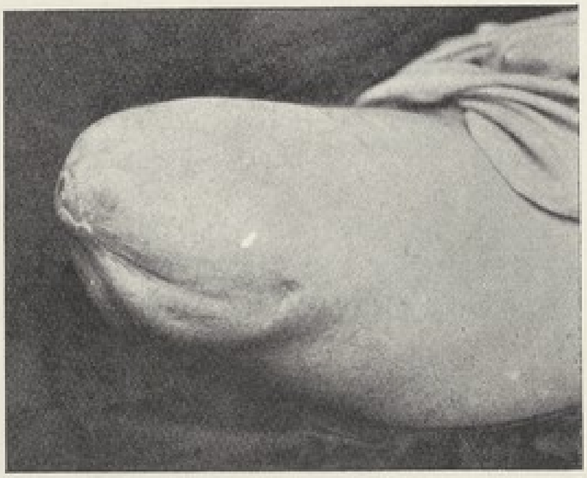


FIG. 32.—AMPUTATION IN MIDDLE THIRD OF THIGH. ADHERENT SCAR.
This scar gave no trouble until a limb was worn, when the drag upon the end of the stump interfered with the blood supply, and the ulcer (shown as a dark mark) at the end developed.

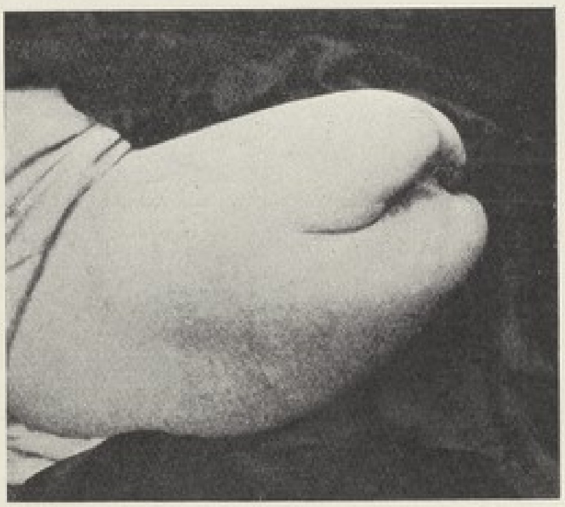


FIG. 32A.—BIFID STUMP, THE RESULT OF ADHESION OF THE EDGES OF REDUNDANT SOFT PARTS TO THE BONE, NECESSITATING EXCISION OF ALL SCAR TISSUE AND EVERSION AND SUTURE OF THE SKIN EDGES TO ONE ANOTHER.

knee, excision of all that remains of the shaft of the fibula will add to the amount of skin available, and sometimes enable the surgeon to cover the tibia satisfactorily without shortening it.

In such operations, if there is still fear of suppuration, the scar should be painted with liquid carbolic acid just before operation and excised well down to the bone, and the instruments used in doing so discarded for the rest of the proceedings. It is always well to drain for twenty-four hours afterwards, preferably by means of half a dozen strands of silkworm gut. No skin grafting operation is to be recommended for covering the end of an amputation stump. The imperfect quality of the resulting covering, and, above all, the absence of sensation in the graft, make it an undesirable mode of closing in the end of a stump.

Deficiency of skin covering of stumps has been common. Less commonly the surgeon has left too much skin, which is

Fig. 33.

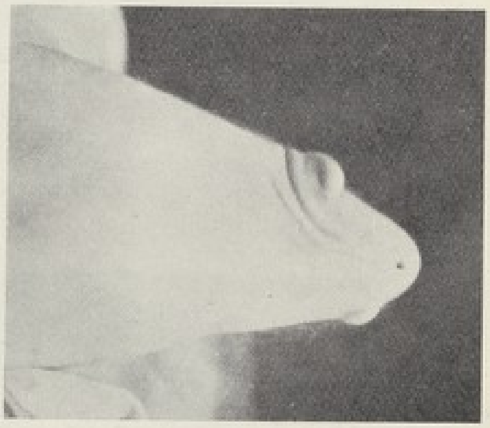


Fig. 34.

thrown into folds which are liable to become sore when a prosthesis is worn, and in some cases are the seat of eczema. An extreme case of this sort is shown in figs. 33 and 34 from photographs kindly taken for me by Major A. A. Atkinson, late R.A.M.C.

Impairment of function of a joint above the site of amputation is a serious drawback. In the upper extremity ankylosis or subnormal range of movement in the shoulders not only reduces the range of movement of the stump, but it also hampers the use of a prosthesis by impairing the sources of power by which the artificial elbow-joint is flexed and locked, and the fingers and thumb extended or flexed.

Similar loss of function of the elbow is, however, chiefly of importance in so far as it limits the movements of the stump, provided that if the elbow is stiff it is fixed in a useful position.

Contracture of the hip-joint is, unfortunately, common in cases of amputation of the thigh, particularly when the stump is short. Most often it is limited to a reduction of the range of extension, and this is sometimes accompanied by diminution of the range of abduction, the stump being outdrawn. Flexion contracture of the hip should be measured after the manner recommended by H. O. Thomas (see fig. 35). The patient lies on his back upon a table (not on a mattress or couch or bed). The surgeon lays the tips of the fingers of one hand under the patient's lumbar region, the thigh stump is flexed fully, and the assistant then flexes

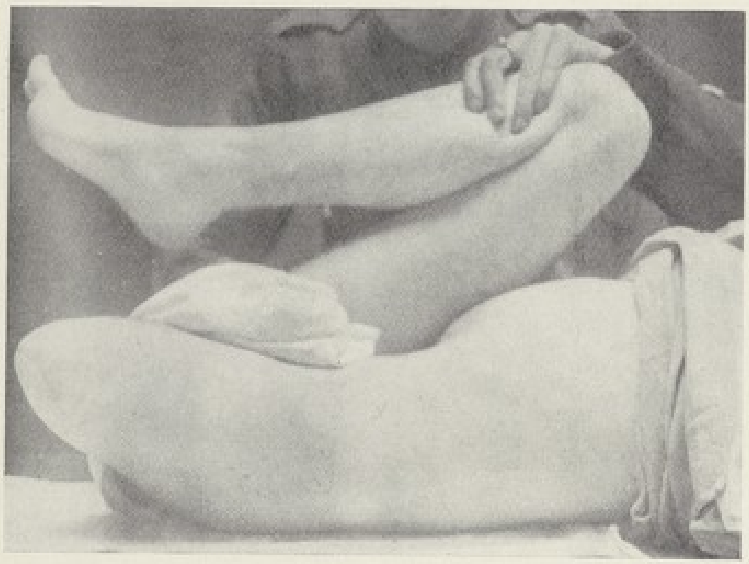


FIG. 35.

the sound knee and hip on to the abdomen until the surgeon feels that the lumbar curve is reversed. (At this stage of the proceedings the surgeon's fingers are in danger of a severe pinch between the spinous processes of the patient and the table if the assistant is too vigorous.) While the assistant prevents extension of the sound hip the surgeon extends the stump, pushing it forcibly downwards as far as possible. The angle which the stump makes with the table is then measured, using the back of the great trochanter and of the end of the shaft as the two points of the line of the stump.

By means of a simple wooden goniometer the amount of contraction is read off in degrees, for purposes of record and for measurement of future progress (see fig. 36). Individuals differ as to the range of hip flexion, and the writer has been in the habit of regarding anything under 15 degrees as negligible from the point of view of the artificial limb maker. Contortionists and indiarubber men afford proof of the extent to which mobility of the hip may be cultivated. Obesity prevents full flexion of the thigh on the abdomen, and in fat persons the measurement is difficult. Stiffness of the so-called sound hip also intereferes with it.

Abduction is measured by the surgeon placing his thumbs on the two anterior superior iliac spines after seeing that they are on the same level ("level" is here used in the sense it would

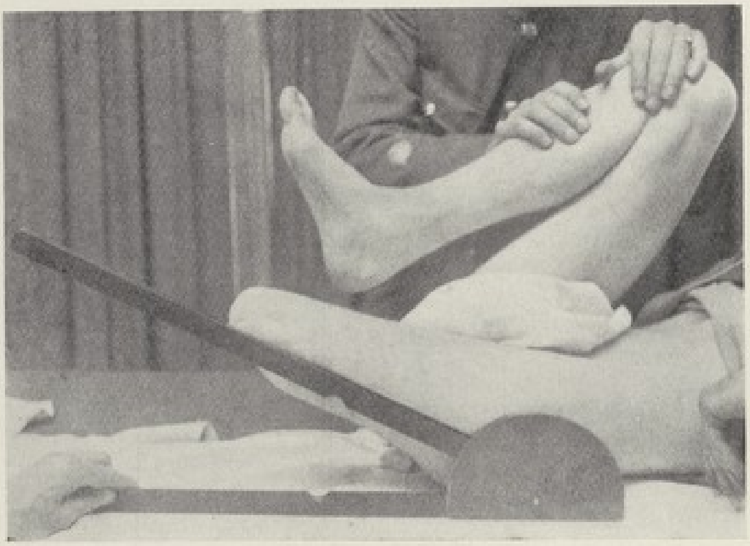


FIG. 36.

have were the patient erect), and the patient is told to bring his stump close alongside his sound thigh without moving the latter. If the anterior superior spine on the side of the amputation is felt to descend with the stump, thereby indicating a tilt of the pelvis, there is abduction contracture. Care must be taken to see that abduction is not masked by flexion when thus measuring.

Some space has been devoted to the above description because contracture of the hip is easily overlooked by the unwary, and is of great importance in the fitting of an artificial limb. If it is not corrected by treatment, or if, proving incorrigible, it is not allowed for and accommodated in fitting the socket or aligning the prosthesis, there will be much trouble for the patient and, indeed, for all concerned. The treatment of this condition consists in passive movements of extension, which are carried out in the above described Thomas's position with the sound hip fully flexed. In some limb hospitals, effort is economized by the use of a simple apparatus, but this, though convenient, is not necessary. If the contracture does not yield to passive movement, resistant bands of fascia and contracted muscles must be sought for and divided, and the correction maintained during healing by weight extension, or by a plaster spica carried up over the lower ribs. The tensor fasciæ femoris is the structure most often resisting extension and adduction. This can be freely divided with a tenotome subcutaneously.

Failing this procedure, it may be necessary by open operation to divide all resisting structures, including the tendon of the ilio-psoas at its insertion. When the stump is not abducted, but simply flexed, the adductor longus is in some cases in fault.

If all these remedies fail, the flexion must be accommodated by the limb maker by shaping and setting the socket on the knee piece so that the axes of the socket and knee piece form a curve, having its convexity forwards.

Ankylosis of the hip in a vicious position is a very serious drawback. If the stump is short, a limb may be fitted without correction of the deformity; but if the stump be long, means must be taken to remedy the ankylosis or, at least, the vicious position. Excision of the joint or, better still, arthroplasty are the means at our disposal. It is needless to say that the latter, if successful, gives the best result, but as an attempt at arthroplasty may fail and result in renewed ankylosis, care should be taken to see that if this occurs it shall be in a favourable position, that of slight flexion. For while for locomotion full extension is the best position of ankylosis, for the sitting down position flexion is convenient. Even after excision, with resulting loose pseudarthrosis, the patient may walk well with a prosthesis, as the weight bearing function of the femur may be eliminated and the stump will be used only as a lever for moving the prosthesis.

Contracture of the knee-joint is of less importance. A patient with a firmly ankylosed extended knee will walk well and with little limp, and not more than 30 degrees of movement is essential for a good gait. A knee that cannot be flexed to at least a right angle is, however, awkward for the patient when he sits down, especially so in crowded conveyances and public places.

Reduction of the normal range of extension is a more serious drawback in the use of a prosthesis, and when there is not osseous ankylosis, passive movements and the wearing of an extension splint are necessary to endeavour to correct the deformity. The slighter grades of flexion contracture are often gradually cured by wearing a prosthesis.

A flail joint after excision may exist in the same limb as an amputation lower down. This rare combination is only likely to occur in the elbow and forearm. The same apparatus which is used to attach and control the prosthesis can be made effective to stabilize the flail elbow.

On Stumps in Particular Segments of the Limbs.

Upper Extremity.

The functions of amputation stumps in the upper extremity are almost entirely confined to leverage.

The end of the stump is not exposed to pressure because, unlike the lower extremity, no superincumbent weight has to be borne, and thrusting movements are not often necessary.

For efficient leverage, the longer the stump the better, and the presence of even an extensive adherent scar on the end of the bone is no hindrance to lever action, so long as the periphery of the stump is covered by sound and not tender skin. Therefore, after guillotine amputations of the upper extremity, no reamputation should be performed with the intention of improving the stump; for the value of every centimetre of bone is great, and even a large adherent terminal scar is no drawback. The anterior and outer surfaces of the end of the stump are those most exposed to pressure, especially in the upper arm.

It follows that in amputating in the arm and forearm as much bone should be saved as possible, without much consideration of flaps; but where the soft parts are abundant, two equal flaps giving a linear end scar neither adherent nor pendulous are to be preferred. In forearm stumps it will generally be found that the bones are in the position of semipronation, in which the radius lies above the ulna and the brunt of the work in moving the socket falls upon the lower part of what may be left of the radius.

Forequarter Amputation.—These cases are rare. Those that have been seen were fitted with much the same kind of apparatus as that appropriate to disarticulation of the shoulder, but such arms are more ornamental than useful.

Shoulder-Joint Disarticulation.—Most of the scars in these cases do not interfere with the use of artificial arms, but the best position is the commonest one—in the hollow below the acromion.

The usual artificial arm is fitted with a shoulder cap and a large bearing surface, therefore pressure is not often troublesome, but occasionally the axillary nerves are involved in the scar on the chest wall and give trouble. There, as elsewhere, the nerves should be cut short.

In cases complicated with burns and consequent scar tissue or damaged skin, difficulties have arisen owing to want of surfaces able to bear continued pressure.

Upper Arm—Upper Third.—An amputation in the upper third of the humerus—that is to say, at a level in the average man 4 inches or less below the tip of the acromion process—affords no stump for the working of a prosthesis. The attachments of the muscles forming the folds of the axilla are situated so low down on the humerus as to make it impossible to insert the upper third of this bone in the socket of a prosthesis. By dividing and turning up the lower parts of the insertions of the pectoralis major, latissimus dorsi, and teres major, something may be gained. It may be necessary in such an operation to slide a flap of skin from the chest in order to cover in the wound. The arm must be kept well abducted throughout the period of healing.

It is only when the stump is just too short to be useful and when the ½ inch of available length is required that this operation is worth performing. It is not advisable if the final result is likely to be a stump of no greater *available* length than 1 or 1½ inches.

Middle Third.—Below the anterior axillary fold a socket can be fitted to even so short a stump (measured from the fold) as 1 inch, which generally represents 5 inches of humerus; but such an arm is of very little use, and it is often better to treat amputations *above* the middle of the humerus as if they were disarticulations at the shoulder, particularly if the patient is likely to be engaged in heavy manual labour. The lower part of the middle third affords a useful stump.

Lower Third.—The whole of this portion of the upper arm gives useful stumps. The best site here is just above the epicondyle. Disarticulation at the elbow-joint is objectionable, as already stated. The special objection at this site is the circumstance that when the socket is fitted on to the stump its end is situated much lower down than the natural elbow. In some occupations this is not objectionable, but clerks and others who work at a desk or writing table complain much of the awkwardness of such an arm,

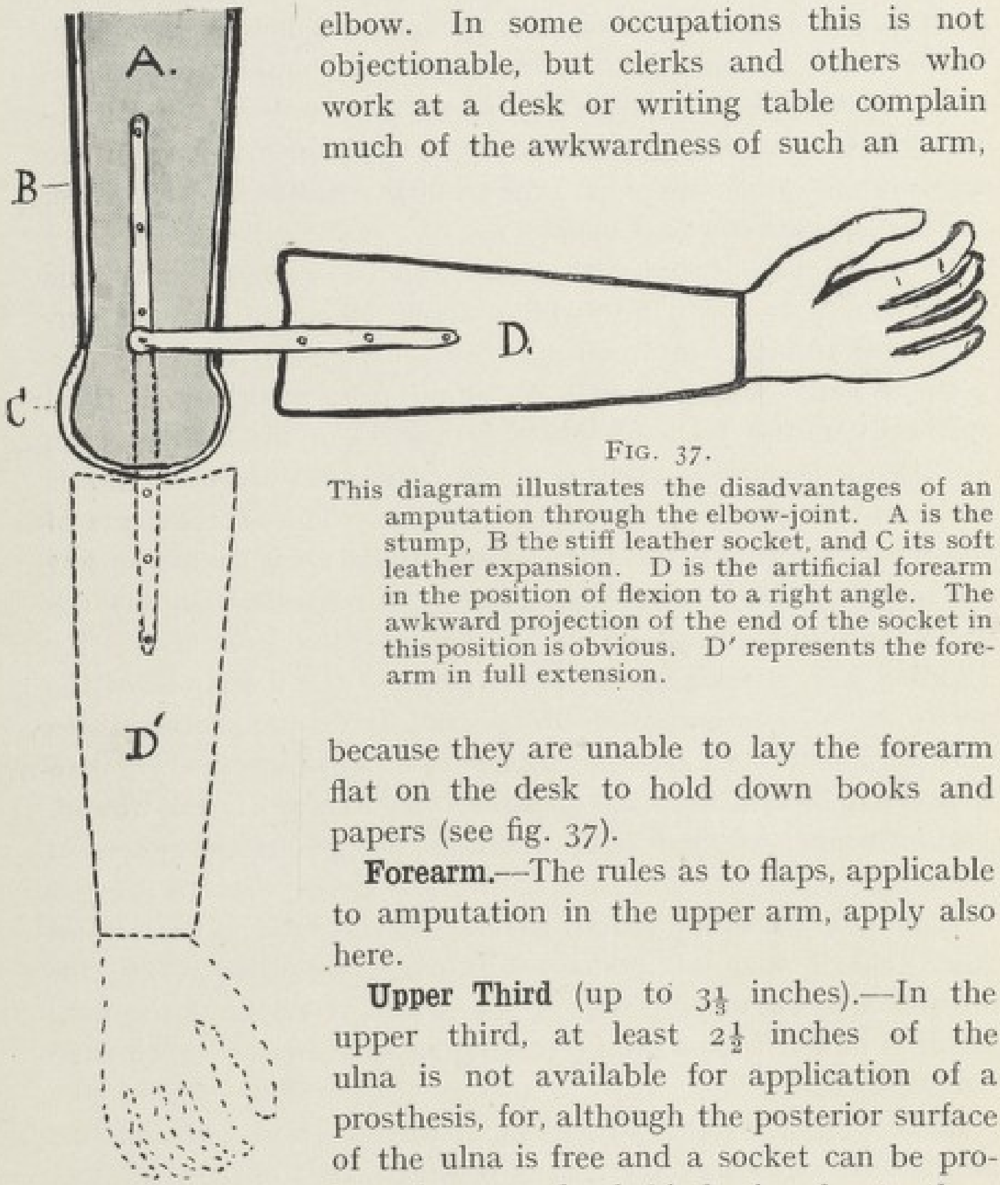


FIG. 37.

This diagram illustrates the disadvantages of an amputation through the elbow-joint. A is the stump, B the stiff leather socket, and C its soft leather expansion. D is the artificial forearm in the position of flexion to a right angle. The awkward projection of the end of the socket in this position is obvious. D′ represents the forearm in full extension.

because they are unable to lay the forearm flat on the desk to hold down books and papers (see fig. 37).

Forearm.—The rules as to flaps, applicable to amputation in the upper arm, apply also here.

Upper Third (up to $3\frac{1}{3}$ inches).—In the upper third, at least $2\frac{1}{2}$ inches of the ulna is not available for application of a prosthesis, for, although the posterior surface of the ulna is free and a socket can be prolonged upwards behind, in front there is no hold to be got below the insertion of the tendon of the biceps into the tuberosity of the radius. This tendon is, of course, of great importance, and cannot be dispensed with.

The lowest inch of the upper third is more or less available, according to the individual's development and peculiarities.

If, however, 3 inches of the ulna at least cannot be preserved, amputation in the lower third of the upper arm, just above the epicondyle is to be preferred. In some such cases it has been thought advisable to take advantage of this necessity to form Vanghetti motors and to cinematize the stump.

The very short forearm stump is useless to actuate a socket, while its presence much hampers the application of a prosthesis, which must be of a special pattern. As the short and useless forearm stump must be included in the upper arm socket, the side joints have to be placed considerably above the end of the socket. In that case little wrong is noticeable as long as the elbow is extended, but on flexion to a right angle or even less the lower end of the socket projects much below the line of the forearm. Not only is this unsightly, but, as before stated anent disarticulation, it prevents the forearm being laid flat on a table in order to hold down or steady any articles such as papers; also, when the end of the stump rests on the table, the shoulder is raised considerably above the level of its fellow.

Middle Third ($3\frac{1}{3}$ to $6\frac{2}{3}$ inches).—The upper part of this section gives stumps which partake of the disadvantage of the upper third, while amputations at any point from 5 inches downward give useful stumps.

Lower Third ($6\frac{2}{3}$ to 10 inches).—The same considerations apply here as in the middle third, but it is more important to preserve supination-pronation movements, as it may be possible with the longer stump to fit a socket which allows of such movement. Amputations should, if possible, be planned so that the ends of the two bones shall not be tied together by scar tissue. Bony union is still more objectionable.

In the lower part of the lower third of the forearm the skin is often badly nourished, cold, or cyanotic, and consequently bears pressure badly. The advantages of a long stump must be weighed by the operator against the disadvantages of the possible malnutrition of the skin. Most often the former will be preferred, seeing that reamputation can later be resorted to.

The objections to disarticulation at the wrist are those common to all disarticulations. Special objections are: (1) That the bones are very liable to be tied together by fibrous tissue so that pronation and supination movements are lost; and (2) that the artificial forearm, when fitted, is likely to be of unsightly length.

Below the Wrist.—From the carpo-metacarpal joints downwards it is difficult, if not impossible, to formulate rules. The only generalizations possible are:

1. That adherent scars on the flexor surface are more objectionable than on the extensor, because the most important movements are flexor, in which such scars would be exposed to pressure.

2. That almost any fragment of a digit may be useful, if not ornamental.

The carpus alone, if movement at the radio-carpal joint is preserved, may be made of considerable use. An end scar is probably the best in this situation. In such amputations the bare stump, which is endowed with cutaneous sensation, is often more useful than any appliance could be. Prostheses in these cases are only worn to conceal the mutilation.

Lower Extremity.

After healing, fat and muscular stumps should be tightly bandaged to promote shrinking of the soft parts, thus anticipating the process which occurs when a prosthesis is worn, and enabling the provision of a second socket on account of shrinking to be postponed. Two crêpe bandages are best for this purpose.

A troublesome form of tinea is often found on the inner surface of thigh stumps and the adjacent scrotum. It is easily cured by several applications of tincture of iodine.

It is surprising that all sorts of unpromising scars in the lower extremity have been found compatible with good locomotion, but the ideal amputation either in the thigh or leg is one with a long anterior flap and a scar behind the end of the bone. The result should be a stump capable of bearing end pressure and also the leverage pressure to which the front of it is exposed in actuating the prosthesis. Moreover, in the thigh the outer side of the lower part of the stump is exposed to pressure, while the inner side is not so exposed to any great extent.

If a thigh stump or, perhaps better, a radiograph of one be examined, it will be seen that the femur lies along its outer side with hardly any muscular covering on that aspect. The bulk of the soft parts of the stump occupy the inner two-thirds of the stump.

This is fortunate, because it is on the inner side that bony spurs are often found, which obviously are ill adapted to bear pressure. They seldom give trouble, and when they do so it will generally be found that the pain is caused by pressure by an osteophyte upon a bulbous internal saphenous nerve (see fig. 38).

Conical stumps used to be condemned. In itself a conical stump should not be objectionable, because a resistant cone would make a good object on which to fit a socket, with good distribution of pressure. But a conical stump is generally one in which the adductor and flexor muscles, having lost their distal attachments, have been allowed to retract, forming a mass often

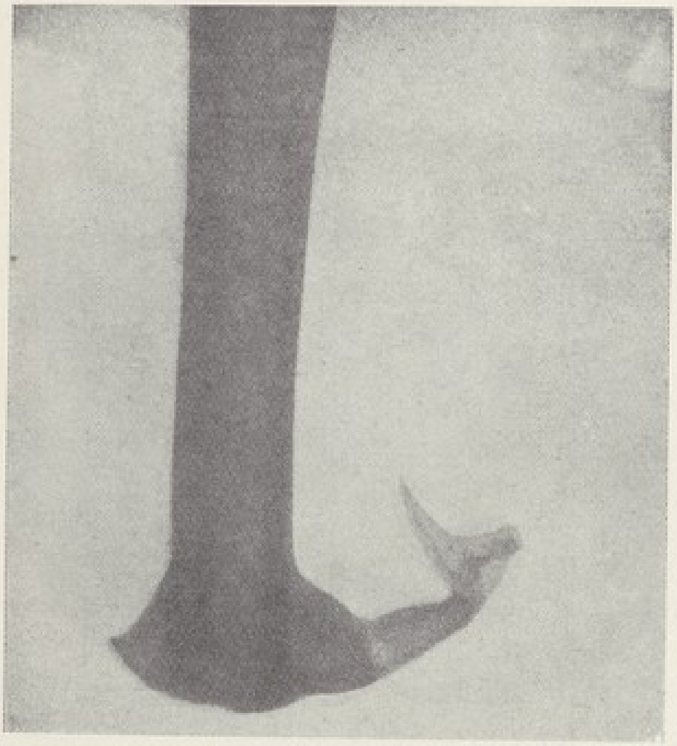


FIG. 38.—MIDDLE THIRD OF THE THIGH: LARGE SPUR ON INNER SIDE, SMALL SPUR ON OUTER SIDE, GIVING NO TROUBLE.

almost hemispherical, or at least fusiform, at the inner side of the top of the thigh. A serious loss of muscular control results, and, furthermore, this mass is apt to get squeezed or nipped by the edge of the socket, and recurrent attacks of painful inflammation of skin and subcutaneous tissue give the patient much trouble. Therefore, whenever it is possible, the tendons or aponeurotic expansions of these muscles should be fixed to the periosteum as low down as possible.

The practice of uniting the tendons or aponeuroses of the flexor and extensor groups of muscles across the end of the bone leads, in those cases in which adhesion to the bone end does not occur, to a scar moving with the action of the muscles in walking. If, as is desirable, an end bearing pad is fitted, the skin of the end of the stump will be exposed to friction each time the muscles contract, and it is likely to become sore.

The experience of the last few years shows that the higher up the thigh we go, the worse (on the average) is the resulting stump, as regards the covering of the end of the bone.

Suitability for end bearing may be taken as a fair indication of a satisfactory stump. The percentage of such stumps out of a series of over 500 lower limb amputations was as follows in the three regions of the thigh:

Upper third	9 per cent.
Middle third	32 ,,
Lower third	77 ,,

The majority of these cases had suffered amputation lower in the limb at least once, and therefore it is only fair to assume that it was only dire necessity in the form of sepsis which determined the sites of the higher amputations, and the nature of the flaps (if any) and the resulting scars.

It is perhaps unnecessary to argue further in the matter. Probably everyone realizes that a thigh stump should be as long as possible, with the exception of the upper 5 inches. Below the knee the case is different, as will be seen later.

In all amputations below the hip or the neck of the femur, and above a Syme, the best scar is a non-adherent one, situated well to the back of the bone. Such a scar is out of the way of end pressure if an end bearing is used, and also of the chief leverage pressure, which falls upon the front of the stump.

Amputations at or near the Hip-Joint.

Stumps after disarticulation at the hip or amputation through the neck of the femur are sometimes seen in which the soft parts are redundant. This is a great hindrance to successful fitting of a socket. The best flap for this stump is a posterior one containing no muscle (the glutæi should be cut short), fitting closely to the pelvis, with no slack, and with the scar close up to Poupart's ligament. The great and small sciatic and the anterior crural nerves should be cut as short as possible. The directions for carrying out this operation, given by Mr. Martin Huggins, F.R.C.S., in his book on "Amputation Stumps" (London: Henry Frowde, 1918), p. 123 *et seq.*, are excellent, and should be studied before undertaking a disarticulation of the hip. If conditions such as sepsis allow, it is preferable to leave the head and neck of the bone *in situ*, carrying the section through the shaft below the trochanters. This simplifies the proceeding, and leaves a better shaped stump than complete disarticulation when shrinkage of the soft parts is complete. However, the presence of septic arthritis will necessitate the complete operation. Such stumps as are left after an amputation by the method of Furneaux Jordan are very difficult to fit on account of the flabby redundant soft parts. If for good reasons such an operation is performed, it should be followed when the patient's state permits, by a secondary resection of the soft parts on the principles above mentioned.

Amputation in the Upper Third of the Thigh.

The average femur being 18 inches long, the upper third will be only 6 inches. An amputation at this level leaves a very short lever for the actuation of a prosthesis, seeing that the upper 3 inches of the average thigh stump is unavailable owing to the disposition of the soft parts. This is particularly noticeable in the case of muscular or obese persons. An amputation which does not leave more than 5 inches of femur is best fitted with a hip-joint prosthesis. In such a case the socket is fitted to take the stump with the femur flexed to a right angle. If the remnant of that bone is much more than 3 inches long it makes an awkward and unsightly prominence in the front of the socket, which makes accurate fitting difficult. An amputation in which the bone-section is made about 3 inches below the tip of the great trochanter—that is to say, through or just below the lesser trochanter—affords a better stump than one an inch or two longer. The end of the bone, when flexed, does not project beyond the general surface of the pelvic stump, and its posterior (under) surface is capable of sharing with the tuber ischii the function of weight bearing if the socket is properly shaped. On such a stump the limb maker can better anchor the pelvic socket than on that left by disarticulation.

Amputation in the Middle Third of the Thigh.

In this region the rules for amputation in the thigh and leg generally apply. Even if the scar be firmly adherent to the back of the bone, the stump is often quite a useful one. One fairly common type of stump with such a scar has been called

FIG. 39.—A COMMON FORM OF THIGH STUMP, ESPECIALLY IN THE LOWER THIRD.

Known colloquially as the "Shark's mouth stump." A good end bearing stump, although the scar is adherent.

"the shark's mouth stump." These stumps have often a good pad of skin and subcutaneous tissue over the end of the bone, which stands pressure well (see fig. 39).

Amputation in the Lower Third of the Thigh.

The considerations referred to in discussing amputation in the middle third apply equally here. The best site is one between 3 or 4 inches above the knee-joint, with, if possible, a hooded anterior flap consisting of skin and all subcutaneous tissues down to the periosteum. The patella should be removed. Some surgeons, however, prefer amputation, through the condyle, which gives a larger bearing surface, but has the drawbacks common to all disarticulations already referred to. The Stokes-Gritti amputation, when correctly and successfully performed, gives good end bearing stumps, but in the experience of the present writer they are no better than the stumps produced by simple amputations. In a large number of cases it has been impossible without the help of a radiograph to distinguish clinically between them and simple amputations above the condyles, and from a prosthetic point of view one is as good as the other. If, however, the patella has not been securely fixed, and has become displaced, the Gritti stump is decidedly inferior. It does not seem, therefore, worth while to prolong and complicate the operation by adopting Gritti's procedures. Fig. 40 shows an attempt at a Stokes-Gritti stump.

Amputations through the knee-joint, while having the drawback of disarticulations in general, have the particular disadvantage of leaving exposed to pressure the roller-like surface of the femoral condyles, which do not always bear that pressure well. When resting on a flat surface, only a very small part of these rollers takes all the weight, and although the end bearing pad

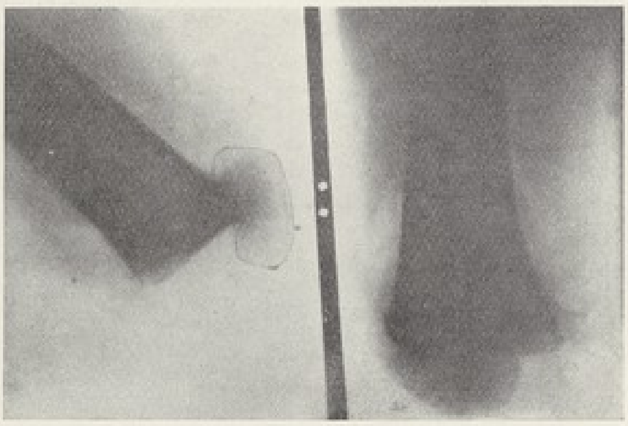


Fig. 40.—Attempt at Stokes-Gritti Amputation.

The cartilaginous surface of the patella has not been removed. The illustration is intended to show the displacement which occurs when the patella is not securely fixed.

may be shaped so as to distribute pressure somewhat, an amputation through the lower part of the condyles, which affords a broad flat surface of cancellous bone, is to be preferred. Among many thousand amputations of the lower extremity examined by the writer at Roehampton, no instance of an amputation through the knee-joint in which the semilunar cartilages are preserved has been recognized. No opinion, therefore, is offered as to its practical value.

Amputations below the Knee.

In all these the fibula, which bears end pressure badly and is often tender, should be divided at a level ½ or ¾ inch higher than that of the section of the tibia. Down to the middle of the leg, say $7\frac{1}{2}$ inches below the upper articular surface of the tibia, the longer the stump the better. Many patients walk very well with very short stumps, even so short as $2\frac{1}{2}$ inches, with a prosthesis skilfully fitted upon modern principles. The old seat of election in the leg was a hand's-breadth below the knee, but it is said that this site was chosen with a view to the use of a kneeling leg. If the stump is so contracted or ankylosed in a flexed position that it cannot be used in a leg socket, amputation in the lower third of the thigh is to be preferred to the kneeling leg stump in most cases.

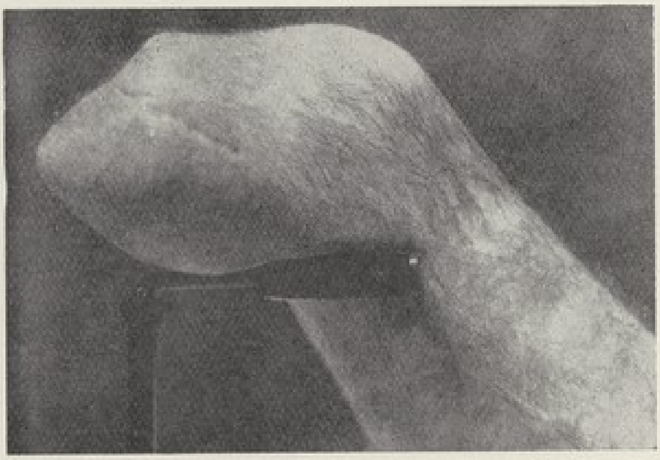


FIG. 41.

A, patella; B, lower end of ridge of shin; C, lower end of posterior border of tibia; from C to D, redundant soft parts.

A certain number of amputations in the upper half of the leg are met with in which, instead of only bevelling off the anterior edge, the surgeon has made an oblique section of the whole bone, thus losing the advantage of the leverage of this part of the tibia, every centimetre of which is of value in a short stump. Moreover, the oblique surface thus left is not suitable for end bearing. When also, as in the figure, the soft parts are redundant, the stump presents a combination of disadvantages. The one in question would have been more useful if the bone had been divided at right angles at B, and if the part of the tibia between B and C had been sacrificed as well as the bulk of the soft parts between C and D, so as to make an end bearing stump with a posterior scar.

Some surgeons have maintained that, owing to the broad surface of bone available for end bearing in an amputation at this level, it is preferable to one lower down, but the experience of all limb makers and most surgeons points to the desirability of a longer lever, the advantages of which much outweigh any disadvantages of the smaller cross-section of bone.

Excluding Syme's operation, amputations in the lower third of the leg are not to be recommended. The bone surface available for end bearing is small and does not stand pressure well, and the circulation in the end of the stump is often poor and the skin cyanotic. This is especially the case when, as has often happened, such amputations are performed for frost-bite gangrene. From the æsthetic point of view, the suitable prosthesis leaves much to be desired, as the lower part of the socket has to be wide and clumsy in order to contain the stump. Theoretically, the extra leverage should be worth preserving, but in practice a patient with a stump of 7 inches is found to walk just as well as one with 10 inches or more.

Syme's amputation, when performed through healthy tissues and followed by aseptic healing, as in the majority of cases in civil life, produces one of the most useful stumps, and one which should be capable of bearing the whole weight of the body on its end without pain. Unfortunately, many, if not most, of the examples of this operation among naval and military pensioners, were performed on septic tissues or for frost-bite gangrene. Many of these are not capable of bearing full weight on the ends of their stumps, and in such cases the value of the stump may be considered as inferior to that of an amputation at or near the middle of the leg, and many patients who have had reamputation performed after wearing prostheses on imperfect Syme stumps have much preferred their latter condition. Before the surgeon decides, however, that a Syme's stump is hopeless, and that reamputation must be done, he should satisfy himself by means of a radiograph that there are no disabling osteophytes, and by careful palpation that no nerve trunks are implicated in the scar. If there is reason to think that any of these are present, they should be sought for and removed by operation. Not only may the main deep nerve trunks be involved, but the larger cutaneous branches such as that of the musculo-cutaneous or the external saphenous may be giving trouble. The stump must not be deprived of all sensation, and if only comparatively large nerves are resected close above the scar, the smaller branches innervating the flaps which come off higher up will not be damaged.

In performing Syme's amputation, a more sightly stump will result if the bone section is made well above the malleoli about ¾ inch above the articular surface. Care must be taken that the plane of section lies at right angles to the line of the leg as a whole, and not at right angles to the incurved lower third. In this way a varus stump is avoided. The flap should not be redundant. The method of dressing the stump after a Syme's amputation has been performed affects the permanent usefulness of the stump. That described by Mr. G. Martin Huggins (*loc. cit.*) is to be strongly recommended.

The æsthetic objections to Syme's amputation remain, however. It necessitates a prosthesis which is comparatively heavy, weighing from 3 to 4 pounds, and the ankle is necessarily clumsy, so that an ordinary boot cannot be worn; and although an ordinary Oxford shoe is applicable, the artificial ankle bulges in an unsightly manner above it.

For working purposes, when appearances are not to be considered, a Syme stump may be fitted with a simple stump boot or elephant foot, for which it is well suited.

There are well-known objections to Pirogoff's amputation, the chief of which from a prosthetic point of view is that it makes too long a stump and leaves too little room for an artificial ankle-joint and foot below it. It appears to have no advantages which are not possessed by a Syme, and has disadvantages of its own. It is, therefore, not to be recommended. The same remarks apply to subastragaloid amputation, and to Handcock's and Tripier's operations.

It is obvious that wounds or disease of the foot may leave the surgeon scant choice of method, and he must often get his flaps where he can. The prosthesis must then be adapted to the resulting stump.

Chopart's operation produces a good sound weight bearing stump, which, however, it is difficult to fit with a regular prosthesis. The commonest fault in these stumps is retraction of the tendo Achillis, whose antagonists have lost their leverage even when the extensor tendons are securely fixed to the periosteum covering the head of the astragalus. During healing the remains of the tarsus should be kept by splints at a right angle to the leg, and it may sometimes be necessary to divide the tendo Achillis subcutaneously to counteract a tendency to talipes equinus. When there is enough skin available, the plantar flap should be long enough to bring the line of suture to the upper edge of the anterior surface of the stump.

Notes on Radiographs of Stumps of the Lower Extremity.

The accompanying reproductions of radiographs of amputation stumps represent some of those forming a collection of 116 prints presented to the museum of the Royal College of Surgeons by the writer.

Fig. 42.

Fig. 43.

In many of them the point of interest is the growth of new bone forming osteophytes or spurs, the occurrence of which has been already referred to.

In other cases the radiograph was taken to clear up doubts as to the nature of the amputation, or to show the results of faulty technique, etc.

Fig. 42 shows amputation through the neck of the femur. The fragment remaining is much abducted, and the lesser trochanter is partially detached and displaced.

Fig. 43 shows a somewhat similar condition, with the formation of much new bone. In both 1 and 2 too much of the neck has been left and operations for removal of bone were necessary.

Fig. 44 is from a case of disarticulation at the hip-joint, which was followed by the growth of a large osteophyte from the wall of the pelvis. This was removed, but the long pendulous stump, consisting of soft parts, still prevented fitting with a prosthesis. This patient has had much trouble from hæmorrhage, and it is not thought prudent to remove the redundant soft parts. As he can bear no pressure on the ischium, and as the whole stump is tender, it is doubtful if he can be made to walk with a prosthesis. This case illustrates one of the problems

Fig. 44.

Fig. 45.

which perplex the surgeon and limb maker. As this radiograph is very faint the osteophyte, pelvis, and soft parts have been outlined on the print.

Fig. 45 shows an osteophyte on a short thigh stump, and

Fig. 46 shows one on a long stump. Neither gave trouble.

Fig. 47 shows a buttress osteophyte in a thigh stump. This form is rare. Perhaps it represents an attempt of the organism to repair the original fracture.

Fig. 48 shows one small internal and posterior spur. The end and most of the periphery of the end of the bone are quite clear. The appearance suggests a tag of periosteum as the cause. This spur gave no trouble.

Fig. 49 represents a femoral stump which has been the seat of periostitis and ostitis. This stump was quite satisfactory for fitting a limb.

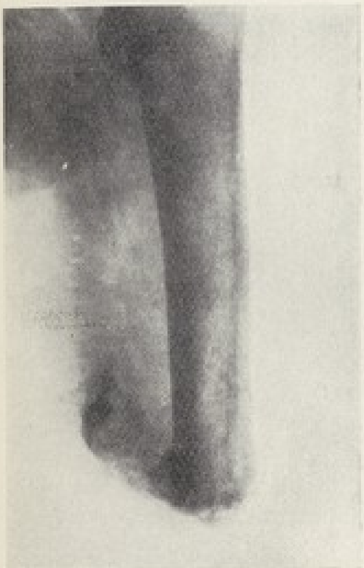


FIG. 46.

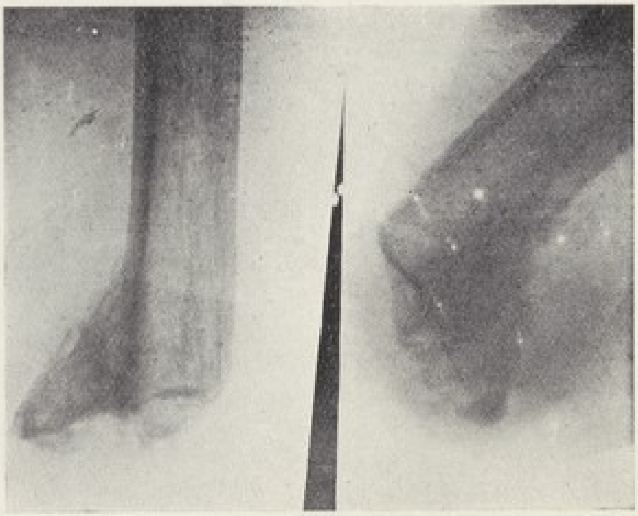


FIG. 47.

Fig. 50 shows evidence of sclerosis of a femur stump, and detached fragments. Despite the unfavourable appearance in the radiograph, the stump is clinically good, and bears end pressure

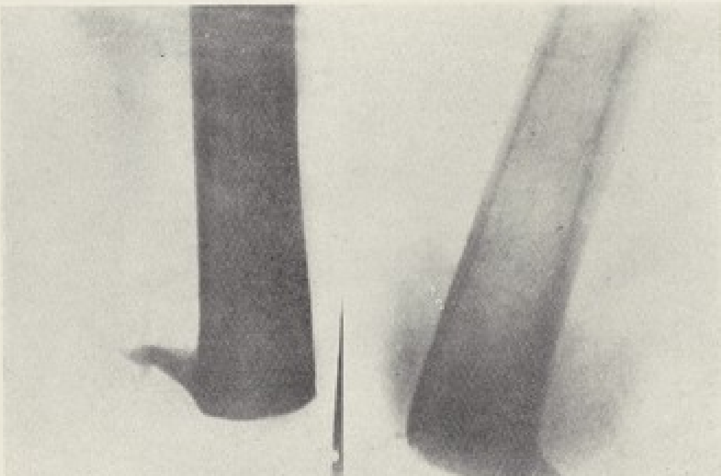


FIG. 48.

well. This is one of many instances of the untrustworthiness of radiographs of stumps as indices of their functional value.

Fig. 49.

Fig. 50.

Fig. 51 shows an amputation through the condyles *à la* Gritti. This operation is now generally abandoned for Stokes's modification. This stump bore pressure well.

Fig. 52 shows a good result from a Stokes-Gritti amputation, but as only one wire was used to fix the patella, the latter has been slightly displaced.

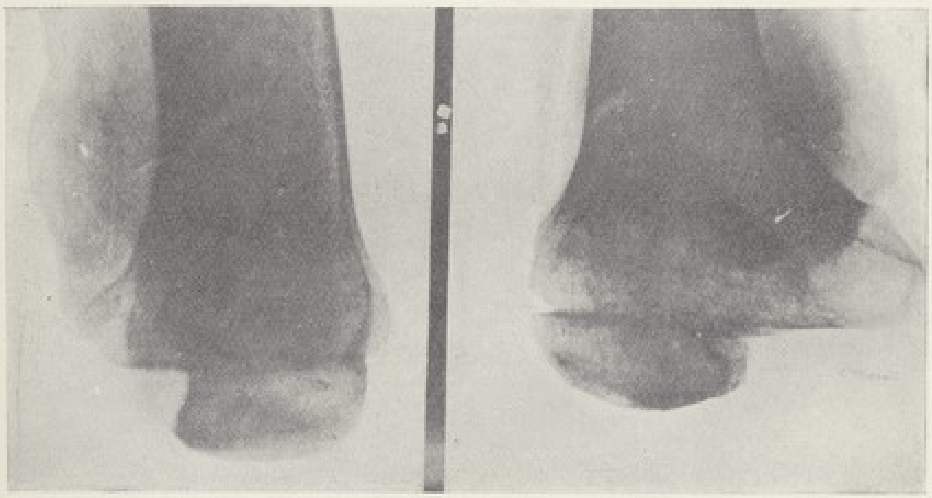


Fig. 51.

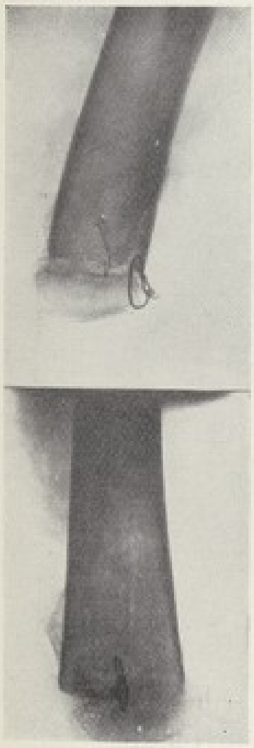


Fig. 52.

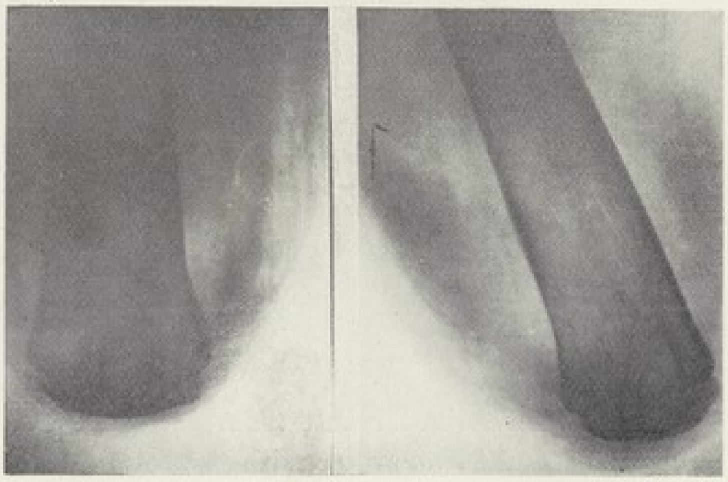


Fig. 53.

Fig. 53 is a good result after the Stokes-Gritti procedure. The patella has been efficiently fixed with two nails.

Fig 54 shows a bad result of Gritti amputation from the operative technical point of view, but the stump clinically was good. The patella appears to be rarefied.

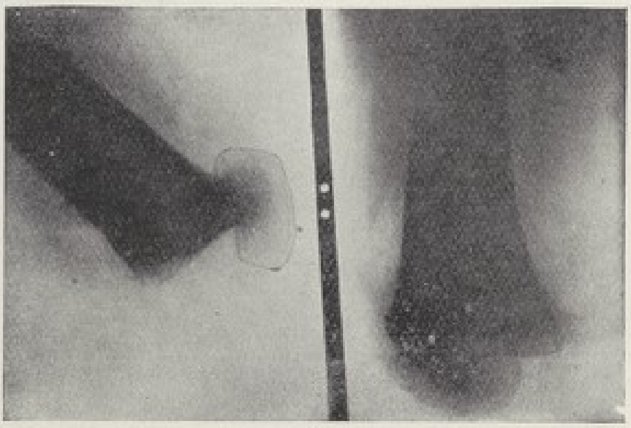


FIG. 54.

FIG. 55.

FIG. 56.

Fig. 55 is a bad result from a Stokes-Gritti. The patella is displaced, not in contact with the femur, and there is a spur and osteo-sclerosis. The ring marks the situation of a sinus leading to the patella.

Fig. 56 is an instance again of a theoretically bad but functionally good stump. The fibula is too long, the tibia very short, and with an osteophyte on its end. This is a lateral view.

In Fig. 57 the antero-posterior view is seen. This is a useful end bearing stump.

Figs. 58 and 59 represent a typical, short, but good below knee stump, which bears weight on its end well.

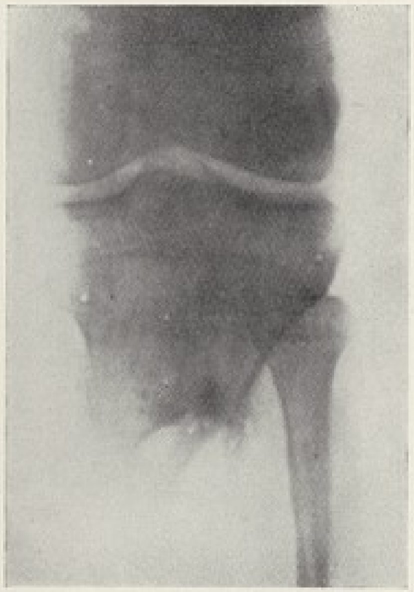


FIG. 57.

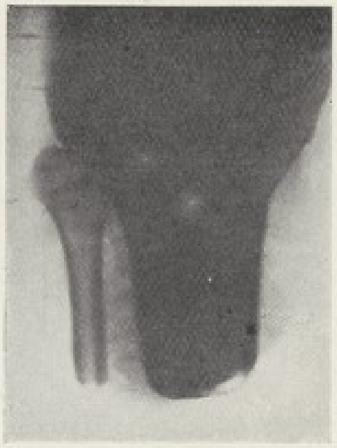


FIG. 58.

FIG. 59.

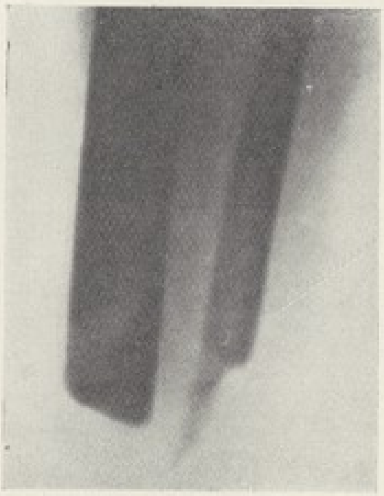


FIG. 60.

Fig. 60 shows a below knee stump of good length, in which the fibula has been cut properly short, but has developed a long troublesome spur requiring removal.

Fig. 61 is the result of a Syme's amputation in which the bones have been divided obliquely. Bad technique.

Fig. 62 represents a lateral view of a Pirogoff's amputation which began to be painful eighteen years after the operation was done.

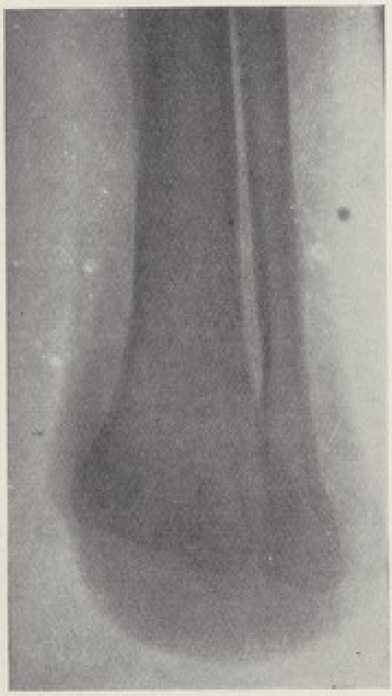


Fig. 61.

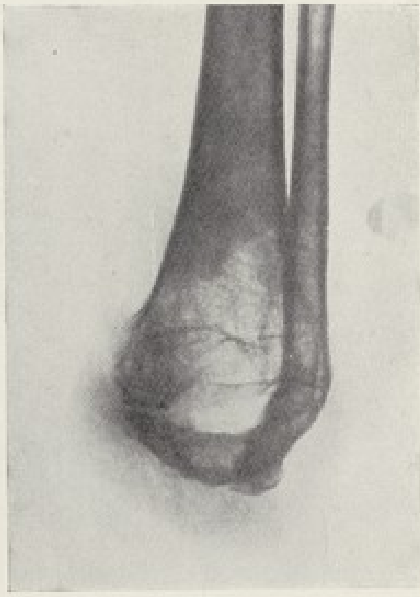


Fig. 62.

Fig. 63.

Fig. 63 shows a Pirogoff's amputation with angular displacement of the fragment of os calcis backwards and upwards.

Fig. 64 shows a more extreme displacement, but extensive bony union. There are several metallic fragments in the stump.

Fig. 64 is a reproduction of a photograph, the exact size of a specimen now in the museum of the Royal College of Surgeons.

FIG. 64.

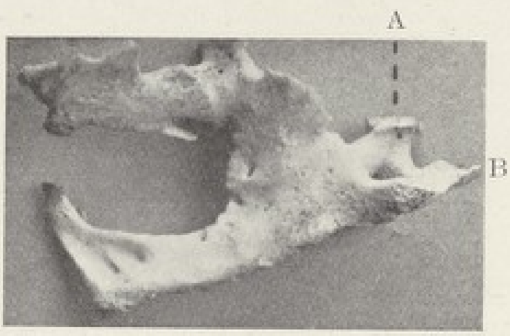


FIG. 65.

The osteophyte here represented was removed by the author from the inner side of a short thigh stump, because unlike most osteophytes in that position it caused pain. It was attached to the femur only by the two small pedicles, A and B, and was imbedded in the adductor muscles. This specimen is numbered

460·2 in the General Pathology Series. The author is indebted for the photograph to the kindness of the President and Council of the College.

Fig. 66. From a case of amputation of both legs. The ends of the bones of the left leg are typical of a good result, but those of the right leg, here shown, have developed outgrowths

Fig. 66.—Anterior View of Right Below Knee Stump.

from both bones, which have joined together forming a V-shaped bridge. Reamputation became necessary, when it was found that the osteophytes from tibia and fibula were very firmly united by cartilage or dense fibrous tissue and not by bone.

This X-ray picture was taken four years after primary amputation.

CHAPTER III

CINEPLASTIC AND OTHER PROCEDURES FOR IMPROVING THE UTILITY OF STUMPS

WHEN, in 1896, the Italian dream of African conquest melted away in the disastrous conflict with the Abyssinians at Adowa, a number of the mutilated victims of the brutality of the victors reached Italy. For although the Abyssinians profess and call themselves Christians, they treated their enemy wounded with horrible barbarity. Eviration—*i.e.*, amputation of the external genitals—was carried out on numbers of prisoners, together with amputation of the hand or hands.

When the survivors of these unfortunates reached Italy, their condition naturally excited widespread pity. For the evirated no prosthesis was applicable, but surgical and mechanical attention was directed to the provision of artificial limbs for those who had lost hands or feet.

In 1898 Dr. Giuliano Vanghetti of Empoli in Tuscany, then a general practitioner, conceived the idea of so modifying the stump by operative measures as to enable its intrinsic muscles to be harnessed to a prosthesis, and thus to actuate the artificial segment.

Dr. Vanghetti is not a surgeon, and he had no opportunity of putting the suggestions of his fertile brain into practice, but he performed many experiments upon fowls, and during the last twenty years his writings have stimulated surgeons to put his principles into practice. To all such procedures he applied the term "cinematization" or cinematic plastic. His suggestions were disregarded for years, for in 1907 Basetta, writing in the *Revue d'Orthopédie*, could only cite two cases of operation, but there were then not less than twenty suggested ways of making plastic motors of muscles and tendons. I will not go into the details of the various methods proposed or practised, but refer to the reports of Professor Putti's lecture in the *British Medical Journal* and the *Lancet* of June 8, 1918, and to the articles by Vanghetti himself, by Stassen, Pelligrini, and Pieri in the *Archives Médicales Belges*, No. 71, p. 657, of 1918.

These four articles give a good account of the whole subject. An illustrated abstract of them appeared in the Medical Supplement of the *Daily Review of the Foreign Press*, issued by the General Staff, War Office, and on sale at H.M. Stationery Office, No. 10, vol. i., October 1, 1918. A monograph in Spanish by Dr. G. Bosch Arana of Buenos Ayres, published in 1920, also gives an account of a number of cases operated upon by that author in the lower as well as the upper limbs, with successful results, especially in the lower extremity. The various kinds of motors may be roughly divided into two classes, the club and the loop. In the former class are all those motors which are meant to be connected with the prosthesis by their peripheries, while in the loop class are all those which are connected by their inner and more central surfaces, such as the loop (in Italian *ansa*, which means a jug-handle), the tunnel, and such like.

The club motor consists of one or more tendons or tendinous expansions, if possible together with a portion of their bony attachment, surrounded by a sleeve of sound skin. A ring is loosely clamped round the neck of this club, to which the cord or other connection with the prosthesis is attached.

In the loop type, on the other hand, a rod or cord is passed through a skin-lined opening in muscle or tendon, or else, as in the case of the jug-handle form, a divided ring is clamped on the skin-covered tendon. Some of these jug-handled motors consist of the tendons of two muscles which are united together to form a loop, much as if two club motors without bone were joined together end to end. It is asserted that besides acting together in one pull, their alternating action can be used by means of two clamps. The writer has great doubt of the efficacy of this arrangement, which he has not yet seen in action.

So far as a limited experience goes, the club motor with osseous nodule in its end gives the greatest promise of usefulness. If it is made large enough and with a large nodule of bone, it is better fitted to stand the pressure of the attachment than is the tunnel, and it can be so planned as to provide a large excursion or range of movement more easily than the tunnel. Also it can be placed at the end of the stump, a position more advantageous than that of the tunnel, which has to be lateral.

The desiderata in a plastic motor are the following:

1. Sufficient muscular power.
2. Well-nourished and innervated skin covering.
3. Ample range of movement.
4. Size—sufficient length and thickness.
5. Appropriate surface for counterpressure covered with well-nourished and resistant skin.

This last condition is important. Unless such a surface is available, the patient's efforts may expend themselves in simply pulling the socket of the prosthesis further on to the stump. Such counterpressure may be exerted against the end of the bone of the stump or against the sides of the wider upper part of the stump, as in the forearm.

The range of movement in the upper extremity should be at least 1 inch; 1½ or 2 inches is preferable. If the range is small the difficulties of fitting are increased, for with a small range with loose fitting there is danger of all the effort being expended in overcoming the back-lash. Again, if the range is small only short leverage can be used, and the effort must be greater. In the case of the two motors being employed for two opposed movements—for instance, the one for extension and the other for flexion of the fingers—the range of movement in the two should be nearly the same, but a difference of range can be accommodated by varying the leverage for the two movements. It is, probably, easier to get a good range of movement with a club than with a tunnel, because the extremity of the club is free, while the distal side of a tunnel is apt to be bound down. This is specially likely if the tunnel is in tendon.

Sauerbruch, who is an enthusiastic tunneller, prefers to make it through the muscular substance. The writer has seen tunnels so tightly bound down that the amount of movement was too little to be of any use. He has, however, seen other tunnels with ample range of movement.

The amputation sites suitable for cinematization are, first, those so close to the joint that the segment below the articulation is of no use to work a socket. By reamputating through the bone above the joint the patient's condition is no worse even if the cinematization is a failure, and the skin of the re-amputated part is available for covering the motors, while the bones are utilized to form end nodules. Secondly, stumps that are too long after amputation through joints, as at the wrist, can well afford to lose an inch or two to make plastic motors.

Most of the cases operated upon in this country fall into these two categories. But were the practical value of the procedure, and particularly of the appropriate prostheses, established, there would probably be few stumps that might not be improved in usefulness by the operation. There is less room for it in the lower extremity than in the upper, because the functions of the leg and foot are simple compared with those of the arm and hand, and they are far more successfully imitated by existing prostheses.

In the upper extremity it seems probable that it will be best to limit the number of motors to two—extensor and flexor. A third motor designed for supination has been added, but there are difficulties in adapting prostheses for more than two motors, which, however, may be soon overcome. After all forms of cinematization it is essential that the power and tone of the muscles should be improved by the frequent use of an apparatus such as a Thomas's splint, to which elastic resistances are fitted and attached to the motors. Such an apparatus serves also to prevent retraction of the motors, and to accustom them to the pressure and friction of the clamps or rods.

When two motors are provided, say, above the elbow, the question arises of how best to use them. Should one be used to move the elbow and the other to flex and extend the fingers against the opposition of a spring, or should the elbow be worked by one of the older methods, and the motors be used in antagonism to one another as flexors or extensors of the digits? Theoretically, the latter method recommends itself, because it seems probable that with use the muscular sense may be so far developed that a co-ordination replacing to some extent the sense of touch may be acquired. If the cinematization hand is to acquire any delicacy of grasp, it seems clear that the spring action must be avoided.

A loop motor may be used simply as a means of attaching the socket of a prosthesis to the stump and to prevent the latter, when very short, from slipping out of it. This has been done in an arm case by Wierzejewski, who also fitted a double-ended hook to the loop so that the patient could carry weights with his stump without the use of any socket or artificial arm, as is shown in fig. 67

(see Medical Supplement to the *Daily Review of the Foreign Press*, vol. i., No. 6, June 1, 1918; and *Zeitschrift für Orthopädische Chirurgie*, Stuttgart, 1916, 36, p. 647).

There have been few cases reported in this country. Mr. Eric Pearce Gould reported two in the *British Medical Journal*, p. 277, 1916. One of them, an officer, was sent to Roehampton

FIG. 67.

to be fitted. He had an amputation of the lower third of the upper arm and one club motor, without bone nodule, connected with the flexors of the elbow.

He wore a clamp on the neck of this motor and an exercising splint with elastic resistance for nearly three months without any trouble, although the end of the club was somewhat cyanosed. Immediately after the artificial hand was fitted he left well satisfied for South Africa, and we have not heard of him since. Major Fitzmaurice-Kelly has operated upon a number of cases, and published a paper on his experiences in the *Lancet* of August 16, 1919. Numerous cases have, it is said, been operated upon by other surgeons in this country, but there are few published records of results.

In the discussion upon Vanghetti's cineplastic amputations at the meeting of the British Orthopædic Association in November, 1919,[1] hopes were generally expressed that a useful working prosthesis for such cases would soon be forthcoming.

The chief difficulty lies in the want of power and sufficient range of movement in the motors. It is true that some motors can lift, when directly harnessed to a weight or a dynamometer, as much as 20 pounds, but this is trifling compared with the force that must be exerted by the normal muscles at the points of insertion of their tendons. The plastic motor, like the natural muscle, must act on a lever at a disadvantage, so that a 20-pound pull may result in a grip of only 4 or 5 pounds. If the lever is lengthened in order to gain power, a longer excursion is needed than can generally be afforded, and mechanical difficulties are increased.

Some German writers have insisted on the necessary distinction between the palmar grasp for large and heavy objects and the finger-end grasp for small and light objects, and they have devised different hands for these different grasps. Many men can exert a force of 35 pounds by the former, and 10 or 15 pounds by pressure between the end of the thumb and index finger in the latter.

Anything approaching this force is not to be hoped for from plastic motors, but for very light work or ornamental purposes prostheses for cinematized arm stumps will probably prove practicable.

Lambret of Lille has described an operation designed to provide a useful stump in cases of disarticulation at the shoulder-joint in which the soft parts are abundant and the deltoid active. With a chisel he removes the spine of the scapula, which has been previously denuded, but left in connection with the soft parts on the outer side. The acromion process is not interfered with. The bone thus freed is rotated through a right angle to the front of the acromio-clavicular joint, and buried in an incision in the deltoid. If the deltoid and pectoralis major are not united by scar tissue, they are to be sewn together. Lambret considers that a useful stump may thus be made, but he records no specific case or any result of operation.

In this country an attempt to graft an artificial humerus in

[1] See *Journal of Orthopædic Surgery*, April, 1920, p. 212.

a case of disarticulation of the shoulder ended in disappointment. Lambret also describes a proceeding for the lengthening of a too short forearm stump; given sufficient soft parts, which can be stretched by preliminary extension, the stump of the radius is to be removed from its normal position and grafted on to the end of the ulna, or a tibial or fibular graft may be employed instead. Unfortunately, however, these ingenious operations do not offer much prospect of providing results of practical value.

Krukenberg ("Ueber plastische Umwertung der Armamputationsstümpfen," Stuttgart, 1917, F. Enke) has attempted to

FIG. 68.—FOREARM STUMP AFTER KRUKENBERG'S OPERATION.

The "tongs" are shown open.

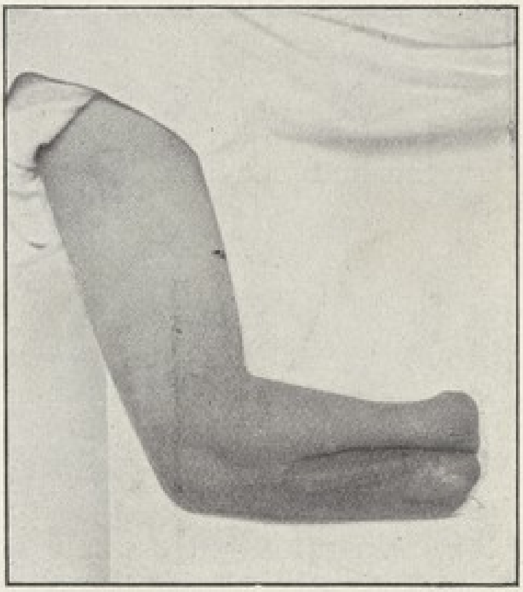


FIG. 69.—FOREARM STUMP AFTER KRUKENBERG'S OPERATION.

The "tongs" are shown closed.

These two figures are from "Ersatzglieder und Arbeitshilfen," Berlin, 1919, p. 256.

utilize the muscles of long forearm stumps in a different manner. His operation consists in splitting the stump, so that the radius and ulna shall form, as it were, the two blades of a pair of tongs. The muscles and their attachments to the bones are carefully preserved or reinserted, those muscles which take origin from both bones within range of the split being carefully separated or if necessary divided. If necessary, plastic methods are employed to cover the adjacent surfaces of the two bones (see figs. 68 and 69). It is claimed for this operation that, although admittedly very unsightly, it provides a very useful prehensile organ, having the great advantage of tactile sensation at the ends of the blades. Artificial hands have been made for these cases, in which the fingers and wrist movements are to be carried out by movements of the tongs, and such an appliance is outlined in fig. 70; but the difficulties of fitting these prostheses so as to provide a useful hand are so great that the double stump must be considered as only useful without any appliance at all. A purely ornamental hand can, of course, be fitted for appearance' sake. It is claimed in Germany that this operation produces results of great value, and that it is justifiable, especially in cases of loss of both hands. So far as is known to the present writer, the operation has not been performed in this country. The one case which came under notice was that of a British soldier, on whom the operation was performed while a prisoner. The result was a failure; the bones were covered to a large extent with skin grafts and scar tissue, and were quite useless. The limb had to

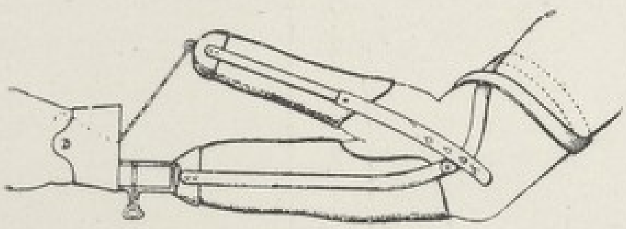


FIG. 70.

be reamputated higher up. This case was misrepresented in the illustrated daily press as one of German atrocity. Lambret of Lille performed a similar operation in 1918, and speaks well of the results of Krukenberg's proceeding (see "Chirurgie Réparatrice et Orthopédique," vol. i., p. 310; Masson et Cie, Paris, 1920).

When the thumb is lost and one or more fingers remain, a useful grasping organ can be made by fitting what is described later as an "opposition appliance," on to which the remaining digit or digits can close and thus hold objects.

Walcher of Stuttgart has in long forearm stumps made a false joint, with the view of applying the above principle. He removes about 7 cms. from the end of the ulna, and makes a false joint in the radius at the same level, separating the bone surfaces by means of a free flap of fascia from the thigh. The tendinous attachments to the distal portion of the radius are left undisturbed, so as to secure active mobility (see fig. 71). A simple socket carrying a plate on the ulnar side is fitted to the forearm.

Objects are grasped between the lower end of the radius and this plate. One obvious advantage of the use of the end of the stump itself for grasping purposes is the possession of sensation, which is a great aid to co-ordination of muscular action. Walcher has reported eleven such operations, with results which are claimed as satisfactory.

In order to improve the usefulness of wrist amputation stumps, T. H. Openshaw has made pseudarthroses of the radius and ulna, so as to produce a factitious carpus on to which a hand could be fitted which should be capable of voluntary extension and flexion. The new carpus can also be used to

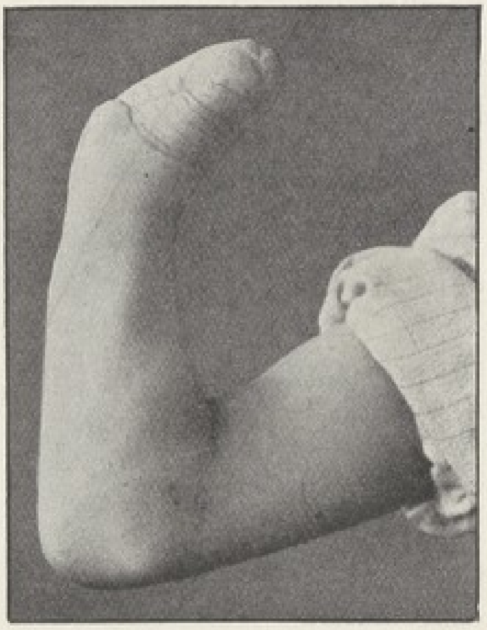


FIG. 71.—FOREARM STUMP AFTER WALCHER'S OPERATION.
From "Ersatzglieder und Arbeitshilfen," p. 253.

open and close artificial fingers by its action. Such pseudarthroses are, unfortunately, very liable to become stiff and useless.

In France Lambret has practised "phalangization of the metacarpals." This operation consists in dividing the tissues between the metacarpal bones with as little injury as possible to muscles, etc., and clothing the cut surfaces with skin. Any surgeon who has had to deal with the operative treatment of webbed fingers will realize the difficulties of this proceeding. The muscular control of the metacarpals may be assured by attaching the tendons of the flexors and extensors of the fingers directly to the bones. Practical experience of this operation is wanting in this country.

The same surgeon has grafted the great toe of a patient who had lost his thumb to the first metacarpal bone. The transplantation must be gradual, by the Italian method, and it is convenient to use the great toe of the opposite side. Lambret says that, although the whole proceeding requires very great care and patience and attention to details, the result is of inestimable value. Such a graft is not likely to be endowed with much sensibility, and in the absence of normal sensation it is difficult to believe that the new thumb can be of great use.

Nicoladoni is the originator of this plan, which has been also carried out by R. Muhsam, who has described the operation in detail in the *Berliner Klinische Wochenschrift*, 1918, No. 55, p. 1045. This writer states that sensation in the new thumb, late great toe, became normal, despite some necrosis and gangrene of the skin. Unlike Professor Lambret, he is silent as to the functional results of his intervention. It is clear that there are no insuperable difficulties in the technique of this operation, but it is doubtful if the game is worth the candle.

J. F. S. Esser also has reported good results after grafting four toes with part of their metatarsal bones on to the metacarpus in place of the four inner fingers (see *Medical Supplement*, II. 2, p. 56).

CHAPTER IV

THE RELATIONS BETWEEN THE NATURAL JOINTS AND THOSE OF PROSTHESES

When an orthopædic instrument or artificial limb encloses a natural joint of the patient, which is to be allowed to move, a mechanical joint has to be inserted in the apparatus. It is important that the centre of movement of the artificial joint should be in the same plane as that of the natural joint, or coincide with it as nearly as possible.

If, however, as often happens, it is impossible to realize this ideal, there will be a greater or less amount of movement entailing friction between the surface of the limb and the artificial appliance.

In the case of a simple hinge joint, such as the elbow or the ankle, if the centres of the artificial joints are on a straight line which coincides with the axis of movement of the natural joint, there should be no motion between the patient's limb and the appliance.

In the case of the knee, which is a combination of a hinge joint with a sliding joint, it is not practicable to fit an artificial joint of which the movements shall exactly coincide with those of the natural joint, although for movements of small range as in walking, the difference should not be great.

In the case of ball-and-socket joints, such as the shoulder and the hip, no rigid joint can be devised which will allow of movement in more than one plane without much discrepancy of motion and consequent friction between limb and appliance. Consequently, if an approximation to the normal movements is desired, the parts of the apparatus above and below the joint are usually connected by means of straps.

This is the rule in the case of the shoulder. In the case of the hip, the artificial limb may be fitted with a pelvic band because of the shortness of the stump and consequent deficient control of the limb.

The following may be taken for practical purposes as the position of the axes of movement of the six principal joints of the limbs:

Shoulder-Joint.—Flexion and extension—a straight line joining the centres of the heads of the two humeri. Ab- and adduction—an antero-posterior line passing through the centre of the head of the humerus. Circumduction cannot be imitated.

Elbow-Joint.—A line passing through the epicondyle and the epitrochlea.

Wrist.—Flexion and extension only—a line through the tips of the styloid processes of the radius and ulna.

Hip-Joint.—In the normal man, standing erect with the feet close together, the centre of the hip-joint is situated on a straight line which passes just above the tips of the great trochanters of the thigh bones, and in front of the whole of each trochanter. The centre of the artificial hip-joint should be in this line.

The decision as to how far in front of the trochanter the joint should be will depend upon the position of the stump of the femur as regards rotation. If it is rotated outwards, the trochanter will be further back than normal, and the joint must be placed further in front of it. If it is rotated inwards, the converse is the case.

If the condition is not normal owing to permanent contraction as follows:

1. In a flexed position, the trochanter will be further back, and the artificial hip-joint must be placed more in front of the trochanter than in the normal.

2. In an abducted or outdrawn position, the trochanter will be higher and the artificial hip-joint must be placed below the tip of the trochanter.

3. In an adducted (drawn inwards) position, the trochanter will be lower and the artificial hip-joint must be placed more above the trochanter than in the normal.

It may be assumed that in the erect position with the feet close together the thigh bone is adducted 10 degrees—that is to say, it is at an angle of 80 degrees with the straight horizontal line joining the centres of the hip-joints.

The tip of the trochanter rises about ½ inch for every 10 degrees of abduction until 120 degrees is reached. Similarly, it falls about the same amount for every 10 degrees of adduction until 40 degrees is reached.

It is not practicable to estimate the movement backwards on flexion, but it is not great, because of the shortness of the radius of motion.

In the diagram represented in fig. 72 the outlines of the transverse section of the pelvis and upper ends of the femurs are traced from the engraving in the classical work of the brothers

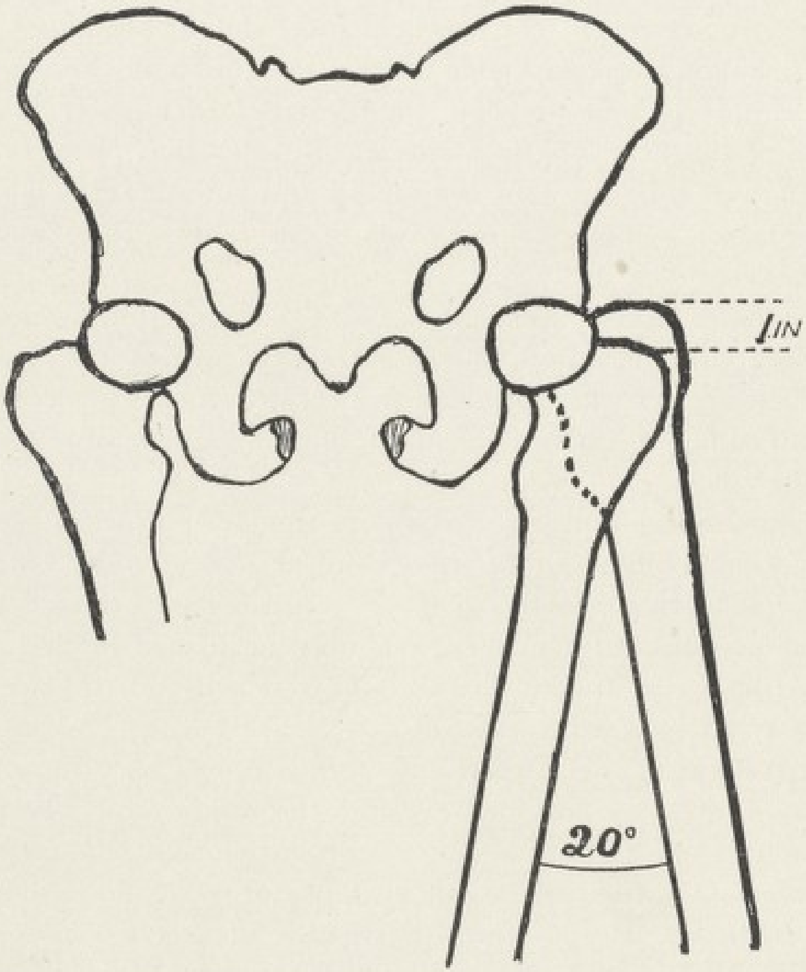


FIG. 72.—DIAGRAM SHOWING THE EFFECT OF ABDUCTION, ETC., ON THE POSITION OF THE GREAT TROCHANTER.

Weber, " Mechanik der Menschlichen Gehwerkzeuge," which are approximately half the actual size. The measurements obtained by using it have, therefore, been doubled to arrive at the foregoing results.

Knee.—A horizontal line passing through the tip of the external condyle of the femur, or at the level of the middle of the patella, and at the junction of the middle and posterior thirds of the knee-joint.

Ankle.—A horizontal line directed outwards and somewhat backwards, passing through the tip of the internal malleolus of the tibia.

The Joints of Artificial Limbs.

Shoulder-Joint.—The shoulder-joint of a prosthesis is rarely made to enclose an active stump and natural joint. When this is done, the centre of the artificial joint should be placed about 1 inch below the lower edge of the extremity of the acromion process. It is well to place this centre rather lower than the centre of the head of the humerus, in order that on flexion the socket shall ride up upon the stump and counteract a tendency of the latter (which in most cases is very short) to escape from the socket.

Prostheses have been made with shoulder-joints designed to allow circumduction, but none are in use in this country, and their usefulness is problematical. Movements of the scapula usually suffice to replace the abduction movement of the normal shoulder-joint.

Elbow-Joint.—For amputations in the lower third of the forearm artificial elbow-joints are seldom needed. Given a forearm stump measuring 6 inches or more from the tip of the olecranon, the elbow-joints of the prosthesis may be placed in the axis of the natural joint, but in shorter stumps it is better to place these joints as far forward as possible.

Wrist-Joint.—This presents no difficulty, as only flexion and extension need be provided for and the joints should be placed in the axis of the normal joint. Pronation and supination are only feasible in the case of long stumps, for which no rigid elbow-joint is fitted. If the stump is capable of active rotation, this movement will take place above the wrist, which the short socket and elbow straps allow freely. In practice it is found that, although many forearm stumps allow of a good range of passive rotation, few have much active force for it. Movements at the shoulder-joint are generally substituted for true pro- and supination.

Hip-Joint.—The centre of the steel hip-joint should be placed above the tip of the great trochanter, and a little in front of it. In estimating this position care should be taken to see that the stump is not rotated out- or inwards, but is in the indifferent position. Most artificial limb makers place this joint much too low. This joint is designed to allow movements of flexion and extension only.

If the centre of the artificial hip-joint is situated at any point on the prolongation of the line above mentioned, its flexion and extension movements will correspond with those of the natural joint, but as regards ab- and adduction and rotation the case is different. The movements of ab- and adduction may be accurately represented by an artificial joint situated on any point on a horizontal straight line passing directly backwards through a point situated about 1 inch below the middle of Poupart's ligament. The movements of rotation, however, can only be accurately represented by a joint situated on a straight line joining the centre of the head of the femur with the intercondylar notch. All movements at the hip-joint, except rotation, must affect the position of this axis relatively to the pelvis. It is, therefore, obviously impossible to have a joint fixed to the pelvis of which the movements will be congruous with the rotation of the natural joint, not only because of the variable relations between the parts, but also because the axis referred to is deeply situated in the limb and trunk.

It is possible to make a hip-joint allowing ab- and adduction and even slight rotation, but in most cases this is not necessary or even desirable, as the patient is unable properly to control these movements with a short stump.

The functions of a pelvic band are not only to keep the prosthesis from becoming displaced upon the stump, but largely to prevent it from swinging about beyond the patient's control, particularly in the direction of abduction. If a joint allowing even a very limited abduction is interposed between the usual hip-joint and the band round the pelvis, the patient, as a rule, has a feeling of insecurity and finds that he cannot control the limb properly.

Knee-Joint.—For amputations through the leg below the knee a thigh corset attached to side steels and an artificial knee-joint on either side is almost universally used (Syme's amputation excepted). As any book on anatomy will show, the mechanism of the knee-joint is very complicated. It has no fixed centre of movement, but flexion and extension are accompanied by a gliding movement of the bones on one another. The rotation movement of the leg on its longitudinal axis may for our purpose be neglected. For ordinary walking it may be assumed that the axis of flexion of the knee passes horizontally and transversely through the tip of the external condyle. The artificial knee-joints should, therefore, be placed on this line or at the level of the middle of the patella and at the junction of the anterior three-fourths with the posterior one-fourth of the joint. Assuming that the thigh corset is a fixture, then, if the artificial knee-joint is placed too far forward, on flexion to a right angle the leg socket will be pushed upwards and forwards against the popliteal space, and a gap will tend to appear in front between the stump and the socket. A similar displacement occurs if the artificial joint is placed too low. The converse result is obtained if the joint is too far back or too high up. In practice, however, the thigh corset is never quite fixed upon the thigh, and when there is no room for the leg socket to slide further up, a substitutory downward movement of the thigh corset will occur, the more so as the tapering form of the thigh favours such a movement.

Ankle-Joint.—The axis of movement in the ankle-joint may be assumed to pass horizontally through the tip of the internal malleolus of the tibia, running outwards and somewhat backwards. In the present connection, however, this joint is of small importance, as it is only in cases of amputations, such as that of Chopart, that the living joint has to be accompanied by a mechanical one.

The normal ankle-joint allows only of flexion and extension, movements of ab- and adduction and rotation taking place in the tarsal joints. Some surgeons think that this movement of rotation round a horizontal antero-posterior axis should be represented in an artificial foot, but this is seldom done. Patients whose feet have become loose, so as to allow of a few degrees of this motion, generally complain of insecurity. It should be remembered that a movement which is useful when controlled by powerful muscles may be a source of weakness in the absence of such a control.

In order to arrive at some estimation of the principles upon which the best practice was based, the following questions were asked in 1919 of eight of the best-known artificial limb makers in London:

"On what principles do you fix the positions of the centres of artificial joints—*i.e.*, what are the relations between those centres and definite anatomical points on the patient's stumps or trunks:

"1. At the elbow for forearm amputations?

"2. At the hip for thigh amputations, not including No. 1 limbs?

"3. At the knee for below knee amputations, not including kneeling legs?

"4. At the ankle in all cases?

"I shall be glad of any statements explaining the reasons for your practice, or for any other information which you may think well to give me."

The answers received were somewhat disappointing. One maker professed inability to answer the questions, adding: "If this were possible, it would be quite a simple matter for any reader of such a paper to become an expert fitter without the practice or training that such have had to go through."

To question 1 only one reply was received: "The tip of the internal condyle" of the humerus.

To question 2 there were six answers:

A. "Five-eighths to one inch above top of trochanter and on outermost part of curve of socket. Rotated in not more than 20 degrees."

B. "Half to three-quarters of an inch above head (*sic*) of great trochanter."

C. "Just in front of, and on a level with, the great trochanter."

D. "Unable to give an exact rule."

E. "Horizontally, the centre of the great trochanter; laterally, ½ inch in front of it."

F. "Practically level with, and slightly in front of, centre of great trochanter."

From these answers it will be seen that the practice varies considerably between that of A, one of the most successful makers, who places the joint as high as 1 inch above the top of the trochanter, to that of F, an equally successful maker, who puts it at the level of the centre of the great trochanter, and adds a note to this effect: "Sometimes it is found necessary to drop the joint a shade below the centre of the great trochanter in order to hold the limb more firmly to the body when sitting."

To question 3 there were six answers:

A. "Level of tip of external condyle." But this maker states *viva voce* that the position is practically determined empirically, both at knee and elbow, by the fitter placing his finger and thumb on each side of the joint while the patient flexes and extends the knee. The point selected is that which is felt to move the least while these movements of the joint are performed.

B. " Half-way between the upper and lower borders of the patella, with the limb at rest and the knee extended."

C. " One and a quarter to one and a half inches above the lower edge of the patella."

D. See answer to question 2.

E. " Horizontally, junction of femur and tibia; laterally, centre of external condyle."

F. " Junction of femur and tibia. For a fat-stump it is sometimes necessary to set this joint slightly above the junction of the femur and tibia when in a standing position, in order to give more freedom to the hamstrings and muscles behind when in a sitting position."

To question 4 the answers were rather vague, as the fact was not made clear that this question only referred to amputations in which the natural ankle was preserved, such as that of Chopart. Only one maker, E, appears to have understood the question, and he replied: " Assume a *via media* line laterally and horizontally between the external and internal malleolus." The question is not of great importance, as the number of cases concerned is not large.

It is to be inferred from the above answers that in the case of the knee the practice is to place the artificial joint too low. The remark of limb maker F in this connection as to his practice in fat stumps is in accordance with the principles laid down above (see p. 82).

The position of artificial joints which do not enclose natural, living joints, but are situated below the end of the stump, is of importance in the lower extremity, and especially in the case of the knee.

In the natural limb the arrangements are such that the erect position can be maintained without any contraction of the muscles and tendons passing over the joint, which, when fully extended, has no tendency to yield forwards (*i.e.*, to flex) under the weight of the erect trunk, because the vertical line through the centre of gravity passes in front of the centre of movement of the joint. It is the aim of the maker of the prosthesis for an amputation of the thigh to place the knee-joint as far back as convenient on similar grounds.

Obviously, the most secure position of the centre of movement would be at the extreme edge of the flexor part of the joint. Thus for the hip in a limb for hip-joint amputation it would be at the front, and in the knee at the back. Such exaggerated limbs have been made, but they are not of practical value, because in the case of a hip amputation it is found preferable to lock the hip-joint so as to allow of no movement in walking, and because a knee-joint placed so far back will not flex at all in walking, but will behave as a stiff joint. The difficulty is generally compromised, as so many questions have to be in prosthetics, and the knee-joint is placed rather behind the middle of the limb. A common type is shown in fig. 73. (Rowley knee-joint), in which the centre of the knee-joint is situated one-twelfth of the antero-posterior measurement behind its middle line. The curvature of the lower end of the knee piece round which the shin piece revolves is an arc of 135 degrees of a circle, of which the centre is the centre of the knee bolt, the posterior 45 degrees of the semicircle being cut off by the line of the back wall of the socket and knee piece, which is continued vertically downwards.

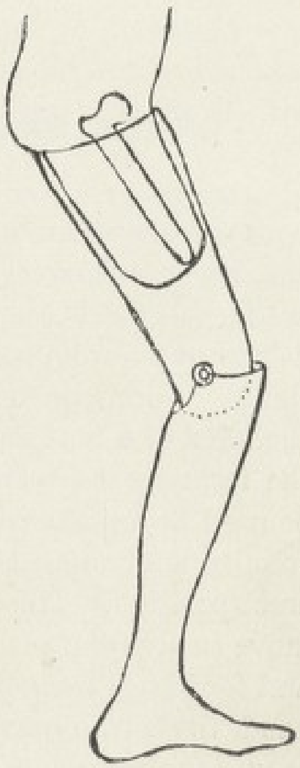


FIG. 73.

In some limbs the centre of the knee-joint is brought still further back by curving the socket with the convexity forwards so as almost to take a scimitar form, as shown in the photograph of a limb by C. Salmon (see fig. 189). In the Desoutter light metal limb and in that made in the Experimental Workshop of the Ministry of Pensions the knee-bolt is placed much farther backwards, with good effect.

The centre of the ankle-joint, which it is not desired to lock in any particular position, is generally placed vertically below the middle line of the leg.

CHAPTER V

ON THE COMPARATIVE USEFULNESS OF ARMS AND LEGS

Arm prostheses are neither so necessary nor so useful as those for the lower extremity. The functions of the upper extremity are far more delicate and complicated, and require a much higher degree of co-ordination of muscles and nerves than do those of the leg. Consequently it is possible to approach more nearly the ideal of a true and complete substitute in the latter than in the former case. The foot of boot-wearing man has ceased to be used as a prehensile organ, and the functions of the lower extremity are confined to locomotion and the maintenance of the erect position. The leg amputee who has no prosthesis cannot move easily from place to place except with the help of crutches, and for him, therefore, a prosthesis is a necessity. On the other hand, those who have lost one arm in many walks of life can do as well with one sound hand as with two, and a number of them have declared, after they have adapted themselves to a one-armed existence, that they hardly knew what they wanted with two hands formerly. Those who have had the misfortune to lose both hands are in a different category altogether. Thus while it is more difficult to make good the loss of one hand or arm than that of a leg, it is fortunately less necessary to do so. To the labourer, however, and to the handicraftsmen whose work is bimanual, a prosthesis is necessary, and the more simple the efforts required, the more useful will it be. The agricultural labourer may be capable, with a comparatively simple prosthesis, of doing a good and hard day's work, equal in some cases to what he could do before his disablement. In France, where so large a proportion of the population works on the land, it has been found that such occupation is best suited to the arm amputee.

The most important factor, however, in the estimation of the value of an arm stump or stumps is the character of the patient himself. Those who have pluck and perseverance—in short, are so fortunate as to be endowed with the will to make good, will succeed in the use of almost any prosthesis, and the better that prosthesis is, the better will their work be. There are others who are easily disheartened after a short trial, or who will not try at all.

It is unfortunately true that a large number of amputees who were provided with arms by the Government did not wear them. An enquiry made by the Ministry of Pensions in 1918 elicited the information that out of 1,746 men amputated above the elbow only 20 per cent. used their prostheses in their occupations; and that out of 737 amputated below the elbow, 48·5 per cent. so used them. Fifty-seven per cent. of the above elbow cases and 30 per cent. of the below elbow cases were engaged in occupations which did not require the use of two hands.

As many of the arms concerned were of old patterns, a second and more detailed enquiry was made in 1919 into the usefulness of 1,354 arms issued in 1917. This enquiry elicited a rather more encouraging report. It is to be noted that of the total number there were more left (717) than right (637) arms. The enquiry cannot, however, be considered complete, as a considerable number of those circularized did not reply.

The institution since this enquiry of systematic training of all arm amputees in the use of their prostheses at limb-fitting hospitals, and the improvements in the design and manufacture of arms, will, it is to be hoped, result in greatly increased usefulness of arm prostheses among the wounded of the Great War. These statistics confirm the conclusion to which most observers had already come, that the problem of the provision of above elbow prostheses is distinct from, and more difficult of solution than, that of the below elbow arms.

In the case of all arm prostheses, the design and details of manufacture present the greatest difficulties, and are more important than the fitting of the socket to the stump.

In leg prostheses, on the contrary, the converse obtains. Fit is more important and more difficult than design and manufacture of the parts other than the socket.

Indeed, it may be said that the crudest and worst type of artificial leg, with a well-fitting socket and well aligned and balanced is better than the best and most elaborate type, if ill-fitted and badly aligned and balanced.

The stump in the upper extremity does not have to bear any upward pressure except in rare conditions. On the contrary, the downward pull of the weight of the prosthesis has generally to be borne by the stump and parts above it.

The principal function of the stump is to act as a part of a lever formed by it and the socket together. The more closely the socket and stump fit, the less *lost motion* between them there will be, and the better the result.

The shorter the stump, the more accurately and closely should the socket fit, especially at its lower end. Slack fitting allows the socket to tilt and assume a position in which its long axis is at an angle with that of the stump. The greater this angle, the more is pressure concentrated upon two small areas, which are likely to become painful and abraded (see fig. 74).

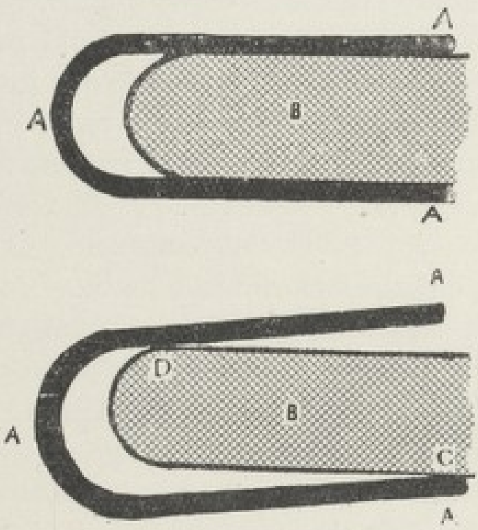


FIG. 74.

In the diagram, A represents the socket, B the stump, and C and D the points of pressure where the socket is too large and is tilted on the stump. The lower figure represents a socket which is too loose, and which is consequently tilted. The upper drawing represents the ideal in which the stump exactly fits the socket, and there can be no tilting. This is unattainable in practice, but it may be approached; and the closer the fit, the less the possible angle of tilt and the less concentrated the pressure will be. This is applicable to legs as well as arms, but is more important in fitting the latter, in which leverage is the most important function of the stump, and weight bearing is eliminated.

The stump in the lower extremity also has to act as part of a lever in swinging its segment of a limb forwards or backwards, and therefore, the more accurately stump and socket fit one another the better; but this is not the most important rôle of the stump in the lower extremity, which is to transmit to the prosthesis the whole weight of the body during locomotion when the foot of the opposite side is not resting on the ground. This weight is felt upon the stump and parts above it as the upward counterpressure of the prosthesis.

This pressure may be, and generally is, borne in two ways—viz., (*a*) by direct vertical pressure between two almost horizontal surfaces such, for instance, as the upper surface of the pad at the bottom of a Syme's prosthesis and the under surface of the end of the stump and (*b*) by oblique pressure, as when a solid cone is forced into a hollow cone such as the stump formed by the tibia and fibula, and a well-fitted wooden socket. Other instances of (*a*) are the under surface of the end of any suitable stump and the so-called end bearing pad, and the under surface of the tuberosity of the ischium and the top edge of a thigh socket shaped to receive it, or the seat formed by the inner surface of a hip socket. Other instances of (*b*) are the surface of the thigh in a below knee prosthesis and the enveloping thigh corset, and the surface of a thigh stump and its containing socket. Even as a prosthesis for Syme's amputation, which most nearly approaches to a pure end bearing apparatus, some weight is taken by oblique pressure between the socket and the sides of the stump. In rare cases of long thigh stump with firm muscles *all* the weight may be borne through oblique pressure on the sides of the stump.

Prostheses are attached to the body by straps of leather or webbing, or in the case of cinematization they may be sufficiently secured by the clamps and cords attached to the motors.

CHAPTER VI

PROVISIONAL PROSTHESES

THESE serve during convalescence after amputation to accustom the stump to pressure, and to hasten by well-distributed pressure the necessary atrophy of the soft parts and shrinkage of the stump. They also serve as a temporary means of locomotion until a permanent prosthesis is fitted, and are also used indoors as a slipper is used instead of boot. The aim of the surgeon in charge of the after-treatment of an amputation stump in the lower extremity should be to avoid the use of crutches altogether, or at least to give it up as early as possible. As soon as the edges of the wound are united and any sutures removed, a temporary prosthesis should be fitted. The early ones are best made with gypsum sockets, which fit evenly and closely to the stump and promote shrinking. These are quite simple and not costly. As soon as the stump has become loose in the socket a new one is made and fitted to the uprights in place of the old, and this can be repeated as often as necessitated by shrinkage. There is only one objection to these gypsum sockets, and that is on the score of their weight. The heaviest part, however, is close to the stump, and thus does not exert much leverage (see figs. 75 and 76).

Another and favourite form of provisional prosthesis is the fibre peg leg, sometimes popularly known as the megaphone leg. This extremely simple, but light and useful prosthesis consists essentially of a sheet of "fibre" rolled into a cone and the edges riveted together, the top of which is suitably shaped and padded to fit the upper part of the stump, while into its lower end is inserted a block of hard wood which rests on the ground. Only occasionally is an end bearing pad used, and in most cases all weight is borne on the upper edge of the socket, as in a Thomas hip splint. For below knee amputations a pair of side irons and rough overlapped knee-joints are fitted, and a short fibre thigh corset. For a method combining a fibre cone with a

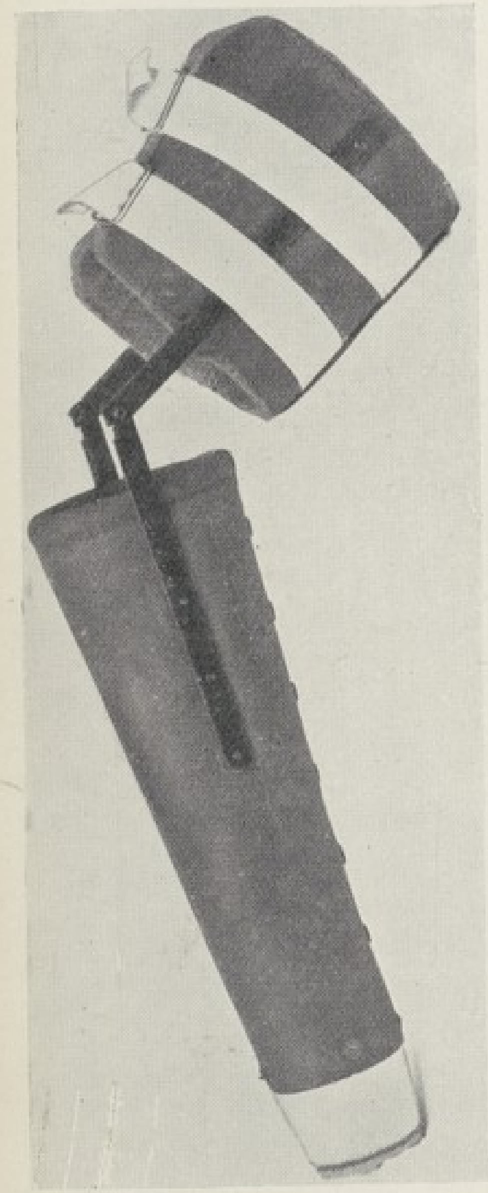


Fig. 75a.—Montgomery Johnston's Gypsum and Fibre Pylon for Amputation below Knee.

Fig. 75b.—Montgomery Johnston's Gypsum and Fibre Pylon for Amputation above Knee.

[To face p. 91.

gypsum socket, see "An Efficient and Economical Pylon," by W. Montgomery Johnston, L.R.C.P., etc., *Lancet*, February 14, 1920, vol. i., p. 374 (see figs. 74A and 74B).

A good provisional prosthesis for disarticulations of the hip is shown in fig. 77, from a photograph of a limb made by the Surgical Requisites Association, 17, Mulberry Walk, Chelsea, S.W. This has a papier-maché socket connected by light side steels, and joints with thigh and shin-pieces of fibre, and with the usual wooden peg.

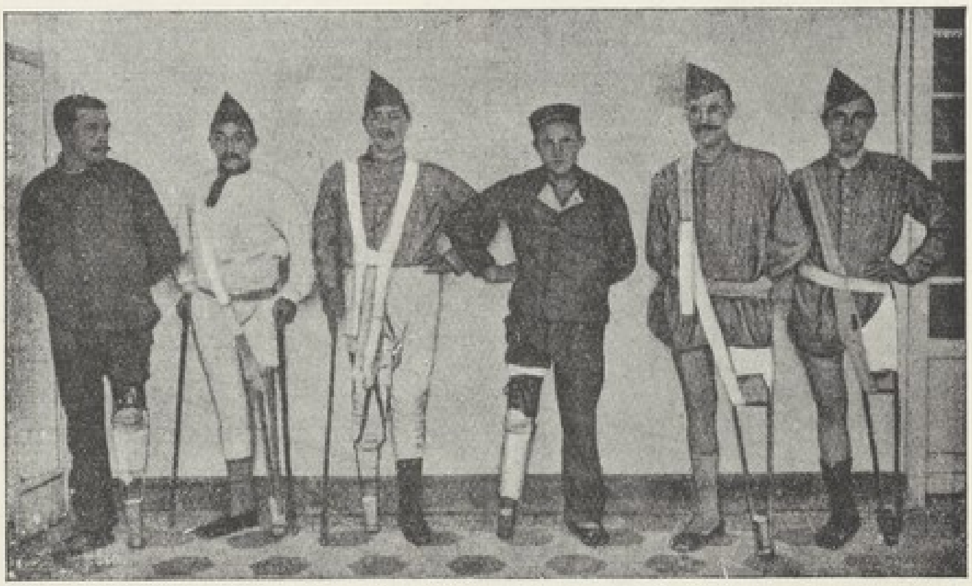


FIG. 75.—VARIOUS PROVISIONAL PROSTHESES OF GYPSUM AND WOOD. By Dr. F. Martin, of La Panne, Belgium. From the *Medical Supplement*, vol. i., No. 6, fig. 65.

It has ring-catch locks at the hip and knee, the latter having a spring which renders its action automatic as soon as the knee is fully extended. The weight of this particular specimen (which is unusually long) is 6 lbs. Although this is only a little lighter than the No. 1. duralumin limb, it is much less costly. It is of value for training purposes, and in some complicated and difficult cases it is useful as a means of ascertaining whether or no the patient is likely to be capable of managing a complete prosthesis.

Provisional prostheses for the upper extremity have been very little used in this country. Yet it would seem that, although not so necessary as temporary peg legs, they are of distinct value as a means of improving the nutrition and developing the power of the stump muscles during the interval which must elapse between the time of healing of the skin wound and that when a permanent prosthesis can be fitted. As in the lower limb, so here, the absorption of the products of inflammation and the atrophy of unwanted muscles are hastened by the pressure of the socket.

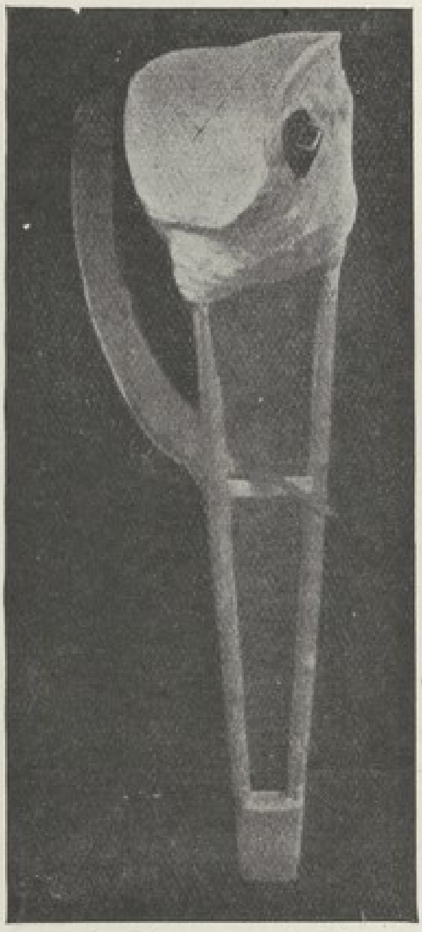


Fig. 76.—Hendrix's Provisional Prosthesis for very Short Thigh Stump or Hip Disarticulation.
From the *Medical Supplement*, vol. i., No. 6, fig. 66.

The provisional peg leg is useful as a means of locomotion, and a very simple provisional arm can be made of considerable use, particularly when the amputation is in the forearm. The early use of such an apparatus prevents the patient from becoming too completely one-armed in his habits, as may happen if time is lost in waiting for a prosthesis.

Biesalski (*Prothesenband der Zeitschr. f. orthop. Chir.*, Leipzig, 1917) has shown how useful improvised prostheses may be made, even for above elbow stumps. A pen or pencil may be fastened to such a stump if of fair length, so that writing may be done with comparative ease, or a spoon or fork may be fixed on, so as to enable the patient to feed himself. This, however, is only needed in cases in which the other hand is disabled or both are amputated. Most men quickly learn to write with the left hand when necessity drives them.

These extemporized appliances may be made of various materials—of pasteboard and adhesive strapping, or of plaster of Paris and iron wire, etc. The " sensible " prosthesis of Spitzy of Vienna for forearm amputations is a provisional arm the principle of which is the conservation of the sensibility of the stump. This is attained by covering it with thin material which protects it from injury, but allows the pressure of external objects to be felt and muscular sense to be regained and used. A simple strap often suffices to attach tools and appliances to this socket.

A simple device which may be used almost irrespective of the condition of the stump, either as provisional or permanent

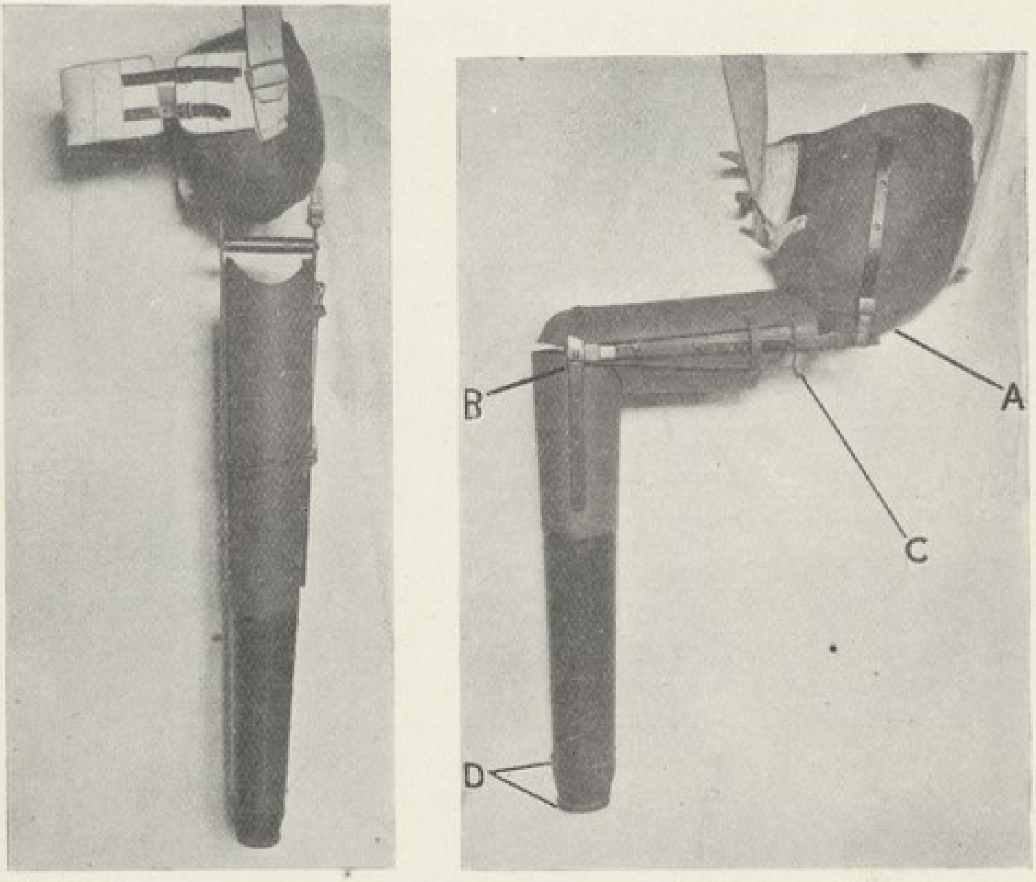


FIG. 77.—PROVISIONAL PEG LEG FOR DISARTICULATION OF THE HIP.

The pelvic socket is made of papier maché. A points to the hip-joint and lock; B to the knee-joint and lock. Both of these are of the ring-catch pattern. C points to the handle which unlocks the knee. D is a wooden block, covered on its under surface with a heel rubber.

appliance, is the so-called "spade appliance" made in Lord Roberts's workshops for disabled men. This is suitable for amputations at the shoulder-joint, or when the arm stump is too short or otherwise unfit temporarily or permanently to carry a socket. It consists essentially of a set of leather straps fastened round the shoulders and attached by a ring or hook or other means to the handle of a spade or other implement, such as a wheelbarrow. It serves to transfer the weight from the implement to the shoulder, and acts as a fulcrum in the same way as the A 1 arm has been described as doing. A similar use of a shoulder harness is described in "Ersatzglieder" (*op. cit.*, p. 667). Such a help for the one-armed labourer can be easily improvised.

CHAPTER VII

ARM PROSTHESES IN GENERAL

THE materials out of which the sockets of arm prostheses are generally made are leather, metal—such as duralumin—celluloid-and-fabric, glue-and-fabric, and wood.

Leather is used more often than any other material. For rigid non-adjustable sockets sole leather is employed, and this is moulded wet upon a plaster cast, constituting what is known as a blocked leather socket. These are commonly used for short stumps. For longer stumps a thinner leather is used, and the socket is opened down the front and closed by means of straps and buckles or eyelets and lace, forming what is known as an adjustable leather socket.

The metal used most generally is an alloy of aluminium. This material has lately been more and more used in the workers' and combined workers' and show arms. No attempt is made to fit these metal sockets exactly to the contour of the stump, but the fit is an approximate one. For the sake of coolness and lightness, the metal is very often perforated.

As aluminium alloys are being more and more used for prosthetic purposes, a few words as to the composition and properties of this metal may not be out of place here.

Pure aluminium unalloyed is generally too soft to be of much use, and the older alloys were too brittle. The alloy used most in this country is known as duralumin.[1]

The composition of the metal is a secret, but it has been put to severe tests, and its properties are well known since it was introduced by Messrs. Vickers, Limited, some ten years ago.

It is slightly heavier than aluminium, having a specific gravity of 2·8, while that of aluminium is 2·7, and of steel 8·0. Its strength is about the same as that of mild steel of the same bulk. Like brass, it can be made stiffer by hammering or rolling, and

[1] See "A New Material for Surgical Appliances," by E. Muirhead Little, *British Medical Journal*, March 3, 1912.

it is supplied in varying degrees of hardness, according to the purposes for which it is required.

It is practically non-corrodible, being scarcely affected by prolonged exposure to a concentrated solution of sodium chloride, ammonium sulphate in 10 per cent. solution, ammonia, sulphuric or nitric acids, sulphuretted hydrogen solution, or sea water. Caustic alkalis, however, attack it quickly.

Duralumin takes a high polish, which is scarcely dulled by prolonged exposure to the air, even to the air of London. It cannot be brazed, but it can be soldered; but as soldering has an annealing effect on it, it is not advisable to use solder. Nor can it be tempered like steel, but the hardening effect of hammering or rolling takes the place of tempering to some extent. Stampings can be made with appropriate machinery, and it can be "spun" on a lathe, but needs frequent annealing during the process to prevent its becoming too brittle.

If, as in soldering, the temperature of the metal is raised to a degree far below its melting point, the rigidity imparted to it by rolling, etc., is lost, and a further raising of temperature, as in casting, burns off the components other than aluminium, so that the properties of the alloy are then lost.

As a result of experiments conducted at the National Physical Laboratory, another alloy has been produced, which can be cast without damage to its qualities. This is stated to consist of:

Copper	4 parts
Nickel	2 ,,
Magnesium	$1\frac{1}{2}$,,
Aluminium	$92\frac{1}{2}$,,
Total	100 parts.

It is claimed for this alloy that its properties are at least as good as those of duralumin, but it has not yet been tried to any extent in the manufacture of artificial limbs.

Celluloid can be made non-inflammable by the addition of calcium chloride in the proportion of 1 in 10, or by adding certain other substances. It has been used for light dress or ornamental arms. This is a similar material to that so extensively used of late years in the manufacture of splints and spinal supports. It consists of successive layers of muslin or similar material, which are dipped in, or brushed over with, a solution of non-inflam-

FIG. 78.

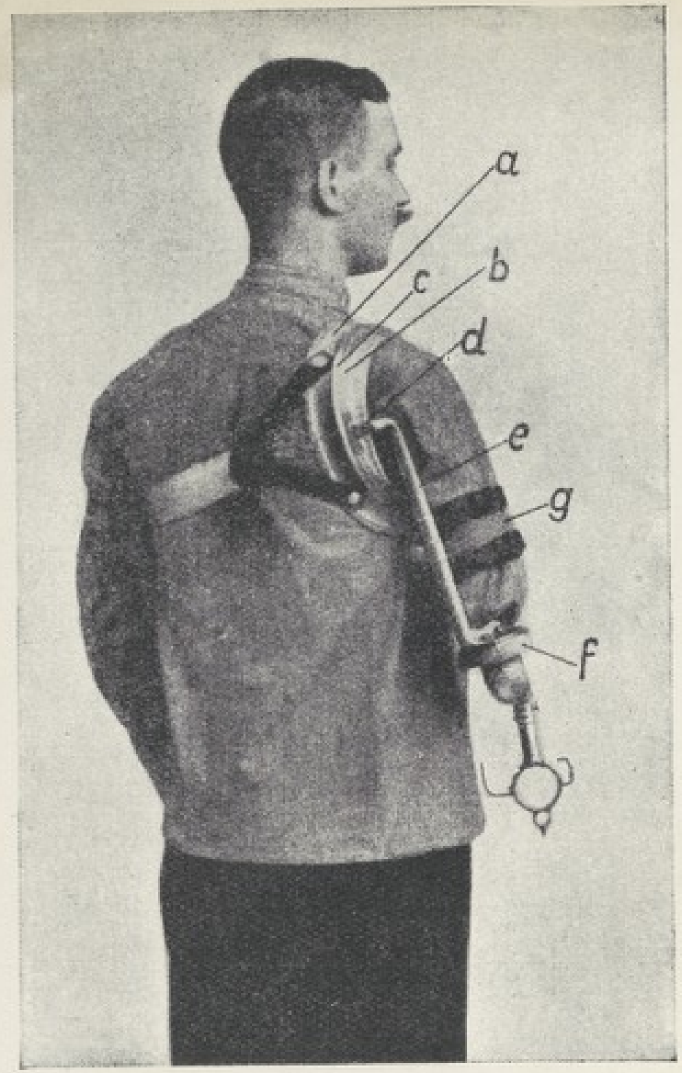


FIG. 79.

a, Shoulder ring attached by a strap round the chest; *b*, ball race, which allows rotation of the appliance; *c*, outer ring of ball race; *e*, *e*, steel tube uprights fixed to outer ring by pivots; *d*, *d*, pivots; *f*, plate connecting the lower ends of the uprights; *g*, straps and buckles attaching the stump to the prosthesis so as to move it.

From the *Medical Supplement*, vol. i., No. 6, fig. 158.

[*To face p.* 97.

mable celluloid dissolved in acetone, applied over a plaster cast in the case of a socket, or over a former or core in the case of a dummy forearm. Each layer is allowed to dry before the next is applied. This makes a light and strong socket, but a stronger and equally light socket is that made of Certus glue and fabric in a similar manner.

This combination, which is the result of experiments made in the Experimental Workshop of the Munitions Inventions Department, is known as Certalmid, and is also used for the sockets of leg prostheses. Certus glue is stated to be prepared from casein, and is supplied in the form of powder. Equal quantities of the powder and cold water are mixed into a cream and applied. The glue sets very hard, and is one of the most tenacious and durable known.[1] Tests have shown that certalmid sockets weigh half as much as those of the same strength made of willow wood and covered with raw hide (see Appendix II.).

Wood is very little used for arm prostheses. The socket of the Carnes arm is made of willow wood carefully shaped, and in some of the older patterns of above elbow arms the elbow-joint, of mortice-and-tenon type, is made of light wood. In other cases where artificial joints are required they are made of steel or of aluminium alloy, with hardened steel wearing surfaces, for these alloys, although as strong as mild steel and resistant to strain, are rapidly ground away by friction of metal on metal.

Arm prostheses may be divided roughly into two classes: the working arm, and the ornamental arm. The former is designed, without any regard to appearances, as a working appliance, and may be used as a tool for work only and discarded at the end of the day's work.

A typical prosthesis of this kind is the German working arm of Siemens-Schuckert, for which a patent in Great Britain was actually granted during the war. As is shown in the illustrations, this is meant to be worn over the clothing and in working hours only, so that it may be laid aside as a mere tool when work is done. It is attached to the shoulder-girdle and not to the stump, which is, however, used as a lever to actuate it. It is shown in figs. 78 and 79.

The ornamental arm is intended to mask as much as possible

[1] The materials for making "Certalmid" for all purposes can be obtained from the General Surgical Company, Limited, of 147-149, Farringdon Road, London, E.C. 1.

the mutilation and to fill the sleeve. There are, however, many gradations between the two types, so that few working arms are not also useful to conceal mutilation, and many ornamental ones are of some practical value.

The simplest form of working arm consists of a socket, generally of stiff leather, fitting closely to the end of the stump, and maintained in position by straps round the shoulders and chest in the case of above elbow amputation, or by straps connected with a laced corset above the elbow in the case of forearm amputation. This socket is fitted closely to the end of the stump, but not so closely that shocks from the use of tools such as a hammer would

Fig. 80.

Fig. 81.

jar the end of the stump. It is strengthened by steels, and carries a steel nipple at the end, into which a hook or other appliance can be fitted. With such a simple prosthesis even an above elbow amputee can do a great deal of hard work in such occupations as agriculture. A long-shanked hook or ring enables him to support the handle of a shovel or other tool. In such a case most of the work is done by the sound arm, the part of the tool held by the prosthesis serving as a fulcrum. The shorter the remaining segment of the amputated limb, the more passive will be the rôle of the prosthesis. Arms of this kind, made by Messrs. Anderson and Whitelaw, are shown in figs. 80 to 83.

The old method of attachment by means of a standard $\frac{3}{8}$ inch

Whitworth screw, which was recommended in the early years of the war by a War Office Committee, is now superseded, and the use of a spring snap catch is becoming general. The advantages of a snap catch are saving of time in exchanging tools, and safety. In the event of the artificial hand or appliance becoming caught in machinery, or otherwise, it cannot be unscrewed in time to save the wearer from danger, but by means of the snap catch any appliance can be instantaneously released and the danger avoided.

FIG. 82.

FIG. 83.

This has actually been demonstrated—*e.g.*, in the case of a man ploughing with an artificial arm and appliance.

The screw attachment has the additional drawback that in movements of a twisting character in the direction of unscrewing the appliance is likely to become loose and the effect of the effort consequently lost. To counteract this it is customary to add a butterfly lock-nut, but this is somewhat clumsy and not very trustworthy. With a good snap catch the appliance can be fixed in any one of several positions so that rotation is impossible, or if desired, it may be so secured that, while in no danger of involuntary detachment, it can freely rotate. There are a good many forms of snap catches. An older form is the keyhole catch formerly much used to attach artificial hands to prostheses. In this the stem on the wrist plate of the artificial hand or the proximal end of the hook, etc., is shaped like a key without wards. It is inserted through a corresponding keyhole in the plate at the end of the artificial forearm, and can be

FIG. 84.—WORKING ARM FOR A GOOD FOREARM STUMP BY ANDERSON AND WHITELAW.

turned round and fixed by a spring in any one of the various points of a circle. This form is, however, hardly strong enough for hard work, and it is not quite so easy to change, because the key must first be in one definite position before it can be inserted into the keyhole, while the other pattern can be equally well inserted in any position. Many ingenious appliances have been invented, some of which are valuable for special purposes and will be described later. The plain steel hook, however, is the most generally useful, and can be put to a very great number of uses by persevering and energetic men.

Such simple arms as those just described are very generally useful on forearm stumps of sufficient length (see fig. 84), but for above elbow stumps their usefulness is limited to a few laborious occupations, and for most kinds of work it is necessary to add an artificial elbow-joint, to which is attached an artificial forearm or a metal rod to take its place. In order that the forearm piece may be held firmly in any desired position an elbow lock is required, which gives the wearer the power of fixation at various angles. In the simplest forms this elbow lock is worked by the hand of the sound arm. This is not always a drawback, but it often happens that the sound hand is already occupied, and that it cannot be spared to adjust the elbow of the prosthesis. It is also difficult to work the elbow lock through the coat sleeve, but this difficulty does not exist when a man works in his shirt sleeves. To meet this difficulty the so-called automatic elbow control has been invented.

In all arm prostheses having artificial elbow-joints it is necessary for the sake of appearances that the elbow should be free when the arm hangs by the side, so that when the wearer walks the forearm shall swing as naturally as possible from the elbow. In all arms fitted with elbow locks, therefore, it should be possible easily to throw the lock out of action so as to allow of this motion.

In some ornamental above elbow arms a strip of elastic webbing is attached in front above and below the elbow. This serves to help elbow flexion, and renders the swing of the arm in walking more natural.

As mentioned in the historical note at the beginning of this work, the method of flexing the artificial elbow by tension of a cord produced by movements of the stump, shoulders, or chest walls is more than a century old. It was elaborated and applied to a number of prostheses by the Comte de Beaufort in the middle of the nineteenth century (see "Recherches sur la Prothèse des Membres," par le Comte de Beaufort, Paris, P. Asselin, 1867).

Limb makers vary in the details of the arrangement of braces, but all of them use the same method essentially. Experience has shown that three "pulls" or sources of power extrinsic to the stump can be made use of, and these are exerted through the medium of cords or thongs attached above to the harness and below to the mechanism of the prosthesis.

These sources are:

1. Movement of the sound shoulder, reinforced if necessary by that of the mutilated side. This movement consists in bringing forward and adducting the shoulder, principally by the action of the pectoral muscles.

2. Expansion of the chest, thereby tightening a belt to which a cord is attached.

3. Movements of the stump of the upper arm, such as flexion and thrusting into, and withdrawal from, the socket. This is, strictly speaking, a shoulder movement.

All these three sources are for above or through elbow amputations, or for the case of a too short forearm stump.

For good forearm stumps which have the use of the natural elbow-joint only two sources are generally used.

Flexion of the elbow-joint is produced in the following manner:

A cord or leather thong is attached at one end to the fore part of the artificial forearm, passes behind a pulley in the upper arm or elbow piece, and is attached above at the back of the shoulder to webbing or leather straps round the shoulders. Flexion at the shoulder-joint will put tension upon this cord, and thus flex the artificial elbow; but it is not always desirable to flex the shoulder and elbow simultaneously, and flexion is best produced by bringing the sound shoulder forward, and thus putting tension upon the elbow control cord.

The mechanisms generally used for the purpose of fixing the elbow-joint in various positions of flexion of the forearm are known as "elbow locks." They all consist essentially of a lever or bolt attached to one of the segments of the limb, which engages in any one of a number of slots or holes in an arc which is attached to the other segment. This bolt is pushed into its engagement by means of a spring, but may be retained out of action by a catch, so as to leave the movement of the joint free and allow the forearm to swing naturally in walking. The lock can always be worked by the sound hand, or, in the case of so-called "automatic flexion" mechanisms, by contraction of some of the trunk or shoulder muscles pulling on a thong or Bowden wire, which withdraws the bolt from its engagement in the arc. In most "automatic release" elbow locks the bolt is necessarily attached to the upper arm and the arc to the forearm. In the

McKay, the Cauet and Hobbs arms, the lock, which is not automatic, but is worked by the sound hand, is attached to the forearm. In such arms the bolt, when released, slides upwards into the arc attached to the upper arm.

The old " flute key " elbow lock, in which a pin carried on one end of a lever at the back of the forearm falls into one of a series of holes in a plate fixed behind the lower end of the upper arm piece, is weak, and is now nearly obsolete.

Having brought the elbow to the required position, to lock it there it is necessary to relax the thong or Bowden wire and allow the bolt to engage.

The bolt is held up by a cord attached below to it and to the braces at the front of the shoulder above. By relaxing the muscles in front of the shoulder-joint, or by flexing the shoulder, this cord is slackened, allowing the spring to push the bolt into a slot or hole in the arc. A very slight movement achieves this, and experts can lock the joint without perceptible movement.

In the older Anderson and Whitelaw A 3 arm a lever elbow lock was concealed in the forearm, and was controlled by a button on the front of it. In this arm the locking lever is placed in the forearm. The joint is unlocked and the elbow bent by tension of one and the same cord. The first effect of a pull on it is to draw the bolt out of the perforated plate. A further pull draws up the forearm. To extend the elbow the wearer gradually relaxes tension on the cord, so as to let the forearm fall, without letting the bolt engage again with the plate before the desired position is reached. This lock can be cut out so as to allow the forearm to swing from the elbow. It is not intended, nor is it fit, to resist great strain.

In the arms of certain makers the elbow is only locked against extension, and further flexion is not opposed. This is often found to be a drawback when, as frequently happens, the wearer wishes to press down on some object with the flexed forearm. It is desirable, therefore, that all elbow locks should arrest both flexion and extension.

In the worker's above elbow arm with elbow-joint and detachable forearm and hand we have a prosthesis which combines utility with ornament, and in some measure conceals mutilation. The forearm portion is detachable below the elbow-joint, preferably by means of a snap catch, so that appliances can be substituted for it, and when so substituted the appliance, instead of being rigidly fixed to the socket, as in the simplest worker's arm, is movable in the directions of flexion and extension automatically (*i.e.*, without the intervention of the sound hand).

A short forearm stump may be long enough to fit into a socket, but it may not be long enough to control the movements of the forearm, or, if it is capable of controlling them for a time, the effort required may be too great and fatigue may rapidly come on.

In such cases it is necessary to help the stump by using the elbow controls similar to those for upper arm stumps, but modified on account of the presence of the natural elbow, which precludes the use of the same flexion mechanism as is concealed in the artificial elbow for upper arm stumps. In this case, as well as in arms for amputation through the elbow-joint, the elbow control mechanism is placed on one side of the joint. By these means the shoulders are enabled to help the stump, and the elbow lock relieves the muscles of the fatigue caused by keeping the elbow flexed, when the nature of the patient's occupation makes this necessary. Unfortunately, the necessary projections at the side of the elbow are apt to wear out the clothing.

Just as the worker's arm for above elbow amputation, with a socket terminated close to the end of the stump, can be converted at will into a quasi-ornamental arm, so a similar socket for a short forearm stump can be converted by substituting for the hook or other appliance a rod carrying an artificial hand, and a leather gauntlet to complete the filling of the sleeve.

CHAPTER VIII

ARTIFICIAL HANDS

Most artificial arm prostheses, and all those issued by the Ministry of Pensions, are supplied with artificial hands, which serve to some extent to mask the mutilation, and which are occasionally useful. It is matter for regret that more than this cannot conscientiously be said of this part of the prosthesis, despite the ingenuity and industry of engineers and limb makers during five centuries, and especially during the last five years. This is hardly surprising when we consider the elaborate mechanism, the numerous muscles, and the delicate co-ordination of the natural human hand, of which the functions, anatomy, and physiology are so well described in Sir Charles Bell's celebrated Bridgewater Treatise intended to "assert eternal Providence and justify the works of God to men."

Since there are fifteen muscles, of which the tendons pass over the wrist-joint to the hand and fingers, and nineteen intrinsic muscles of the hand, making thirty-four in all—and that under the control of the will the hand can be rotated, flexed, extended, abducted and adducted, and the fingers and thumb flexed, extended, abducted and adducted, either singly or altogether, with the greatest nicety of adjustment—it must be evident that the task of the maker of artificial hands, who has at most only two or three sources of power at his disposal, is not a very hopeful one, even with such assistance as cinematization of stumps may be able to offer.

The best and the most elaborate artificial hands as yet invented provide only a simple grasping movement of flexion and extension, all the fingers together acting as one jaw of a forceps, and the thumb as the other.

Since artificial hands are supplied with all arm prostheses, and as with few exceptions any type of hand may be fitted to any arm, it will be convenient to describe them before going on to particulars of the various arms.

An important consideration in the design of artificial hands is the desirability of making them as light as possible. Since the hand is situated at the very end of the lever, every ounce of weight makes itself very distinctly felt. This is more particularly important when dealing with upper arm stumps or with short forearm stumps.

Some writers on the Continent have laid stress on the importance of recognizing two kinds of hand-grasp, and of making hands accordingly.

These are the broad or palm grip for large and heavy objects, in which all the fingers and thumb and the palm of the hand take part; and the finger-tip grip for small objects and light work, in which only the tips of the thumb and of one or two fingers are concerned. If artificial hands were of more practical use, it might be worth while to design and supply these two types of

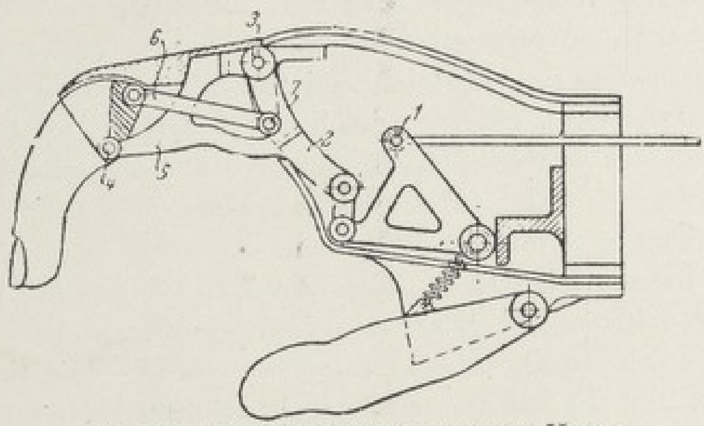


FIG. 85.—THE SIEMENS-SCHUCKERT HAND.
(*Medical Supplement*, vol. i., No. 6.)

hands, but it may be pointed out that the copper-cored fingers of the McKay and Blatchford hands can be adjusted to both types, while the Pringle-Kirk hand is chiefly a broad grip one.

Examples of broad grip hands made in Germany are seen in figs. 85 to 90, which represent the mechanism of the Siemens-Schuckert, the Sauerbruch, and the Müller hands. The finger-tip grip is shown in the simple Sauerbruch mechanism in fig. 91.

The wooden hands commonly supplied with arm prostheses are usually made out of lime wood, and are of two kinds, of which one—the fully articulated hand—has mortice-and-tenon joints corresponding to the metacarpo-phalangeal and interphalangeal joints of all the fingers. These joints are fitted stiffly, so that when any position is imparted to them they will retain it against a moderate force, thus, for instance, making it possible to carry

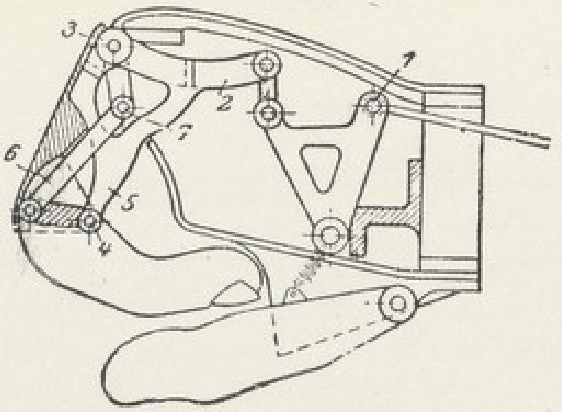


FIG. 86.—THE SIEMENS-SCHUCKERT HAND.
(*Medical Supplement*, vol. i., No. 6.)

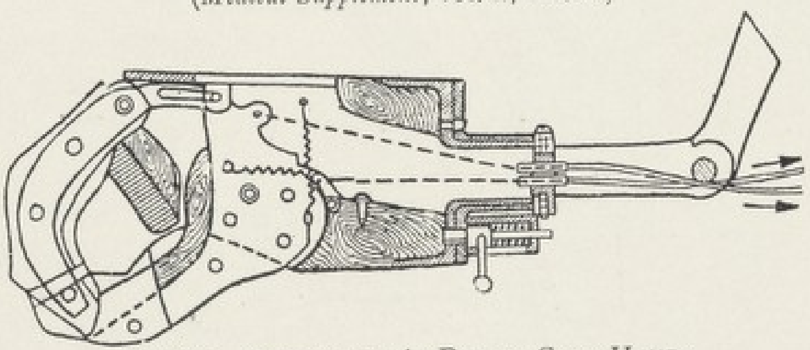


FIG. 87.—SAUERBRUCH'S BROAD GRIP HAND.

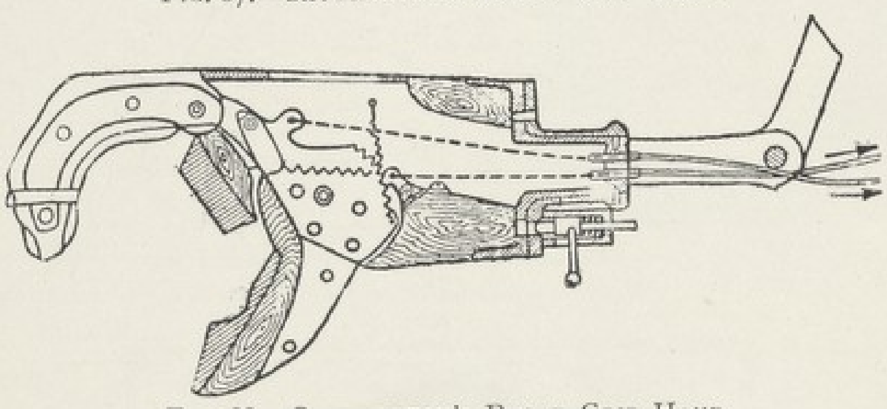


FIG. 88.—SAUERBRUCH'S BROAD GRIP HAND.

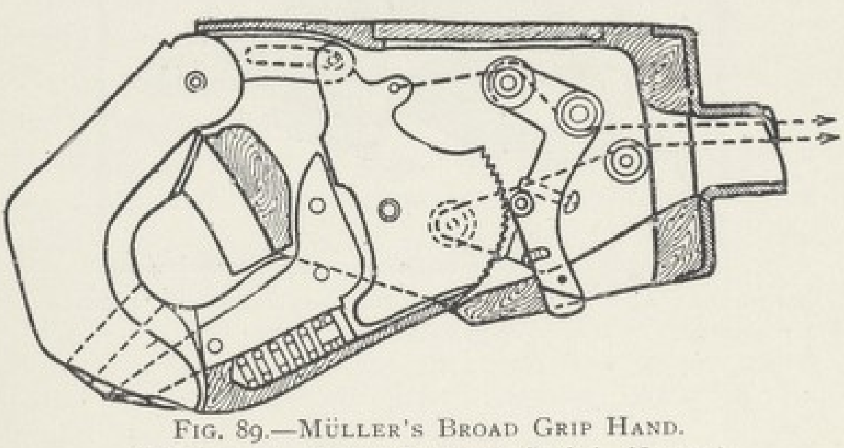


FIG. 89.—MÜLLER'S BROAD GRIP HAND.
(Figs. 87-89, *Medical Supplement*, vol. i., No. 11.)

light objects on the bent fingers up to as much as 10 pounds in weight. In the other kind there are no joints in the fingers,

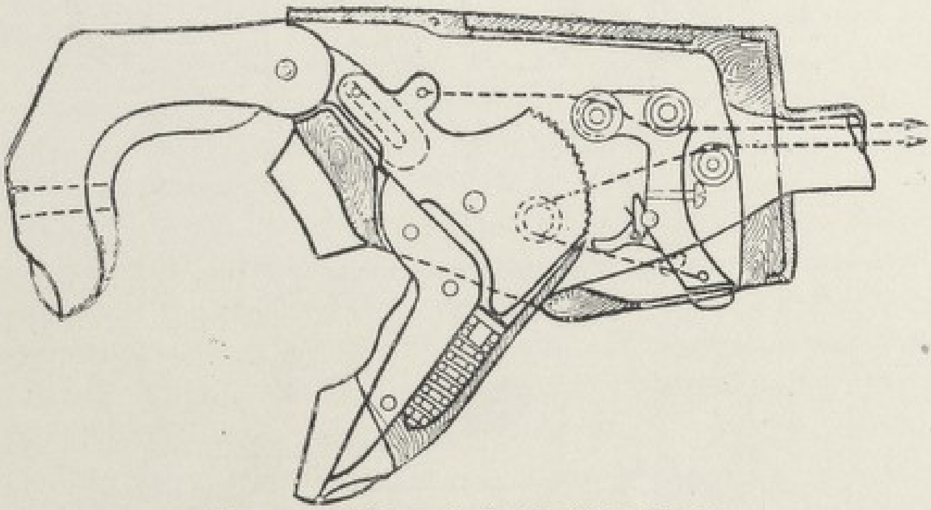


FIG. 90.—MÜLLER'S BROAD GRIP HAND.
(*Medical Supplement*, vol. i., No. 11.)

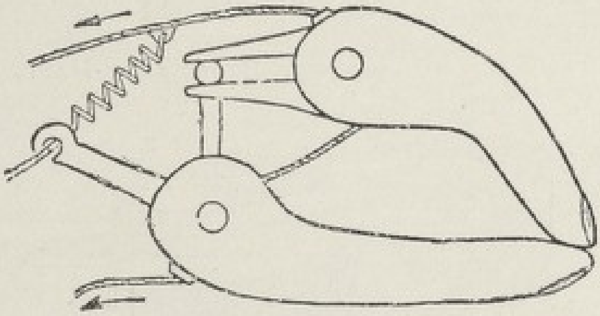


FIG. 91.—SAUERBRUCH'S FINGER-TIP GRIP HAND.
(*Medical Supplement*, vol. i., No. 11.)

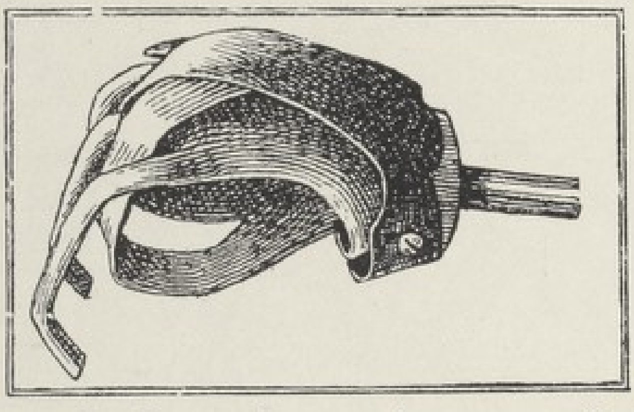


FIG. 92.—THE KELLER CLAW FOR AGRICULTURAL LABOUR.
(*Medical Supplement*, vol. i., No. 6.)

which are carved, together with the hand, out of one piece. The fingers are strengthened with longitudinal tenons of hard wood, and are all more or less curved, so as to serve as carrying hooks. In both kinds of hands the thumb is hinged at a point approximating to the metacarpo-phalangeal joint, and is kept flexed, or rather adducted, by an internal spring. This spring presses the end of the thumb against the radial side of the forefinger or the tips of the first two fingers. Thus the thumb and forefinger act as a spring clip, which may be opened by the sound hand or by means of a cord attached to the base of what represents the first phalanx of the thumb. This cord is connected by a thong or Bowden cable with the shoulder control.

For carrying purposes, the ring and little fingers are modelled, flexed into hook form, and may be strengthened with a metal plate or plates (see fig. 93).

A hole or recess is often made in the palm of the hand near the thumb, large enough to receive the end of a fork, or pen or pencil, and thus to steady it while it is gripped by the spring thumb and fingers.

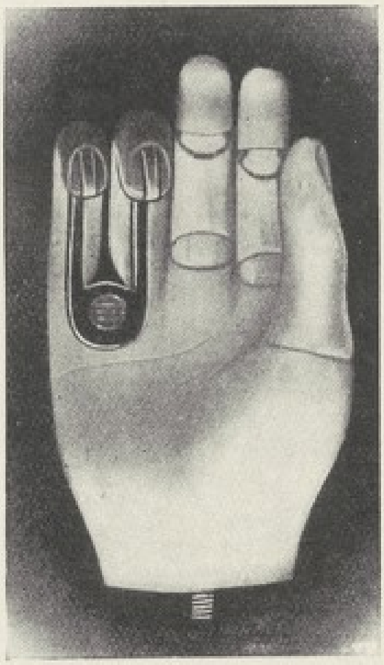


FIG. 93.—THE OPENSHAW HAND OF ANDERSON AND WHITELAW.

It has the usual spring thumb. The fore and middle fingers are articulated, and the ring and little fingers are carved in a position of flexion without joints and strengthened with a metal plate for carrying purposes.

The above-mentioned method of spring grip is common to a number of patterns of artificial hands, in some of which the fingers as well as the thumb are flexed in a similar manner. This may be called passive closure as contrasted with the active muscular action by which extension is effected. It would, of course, be possible to reverse the proceeding, making the spring extend (passively) and the stump muscles flex the digits (actively). The objections to this are obvious, for while the momentary effort of opening may be carried out and repeated without much fatigue, to maintain the grip by active contraction of the muscles would be too fatiguing. Moreover, the continued contraction of certain shoulder muscles would be inconsistent with the free movement of the stump. Another argument against the plan of passive spring extension is that when at rest in the extended position the appearance of the hand would be unsightly, and the fingers or thumb would be likely to become entangled with surrounding obects.

Unfortunately the (passive) spring closure can have no greater force than can be overcome by the stump muscles concerned, and as these act on the hand at great mechanical disadvantage the force available is small, and the grasp gives way rather easily. For this reason devices for locking the fingers when closed and for releasing them at will have been introduced.

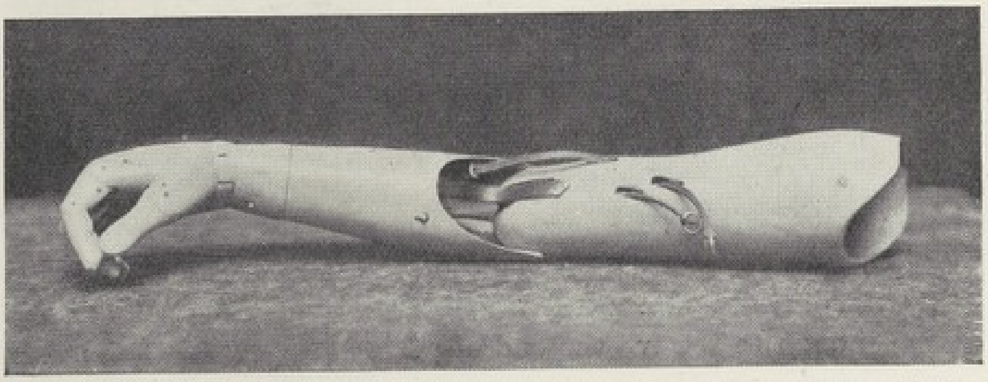


FIG. 94.—CARNES ARM FOR ABOVE ELBOW AMPUTATION.
(From a photograph.)

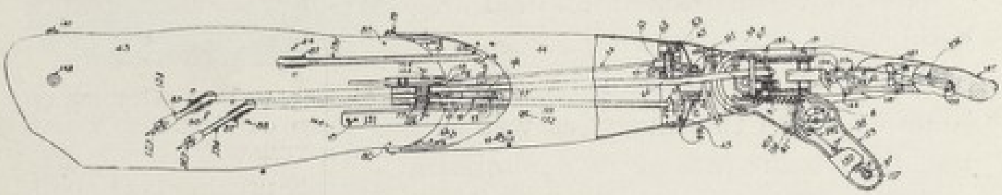


FIG. 95.—MECHANISM OF CARNES ARM FOR ABOVE ELBOW AMPUTATION.

There are two types of hands among those issued by the Ministry which cannot be removed at any moment and replaced by appliances such as a hook or vice. These are the Carnes and the Pringle-Kirk hands. The well-known Carnes artificial arm is a wonderfully ingenious machine; but the hands, which are made of steel, have the disadvantage of being heavy, weighing, according to type and size, from 16 to 24 ounces. On the other hand, they have the advantage of adaptability to various positions, which enormously increases their usefulness. The hand can be fixed in various positions of flexion or extension of the wrist by a simple adjustment made by the sound hand. Similarly, it can be placed in pronation or supination. Most detachable hands can be fixed in a number of positions of various degrees of supination or pronation, but they are generally worn in semipronation, so that when they hang by the side the thumb is in front, as in the natural position of rest starting from this position. In the Carnes arm, flexion of the elbow is accompanied by supination of the hand at the wrist-joint, so that as the hand is brought up to the mouth, for example, the palm instead of the radial border is turned towards the face.

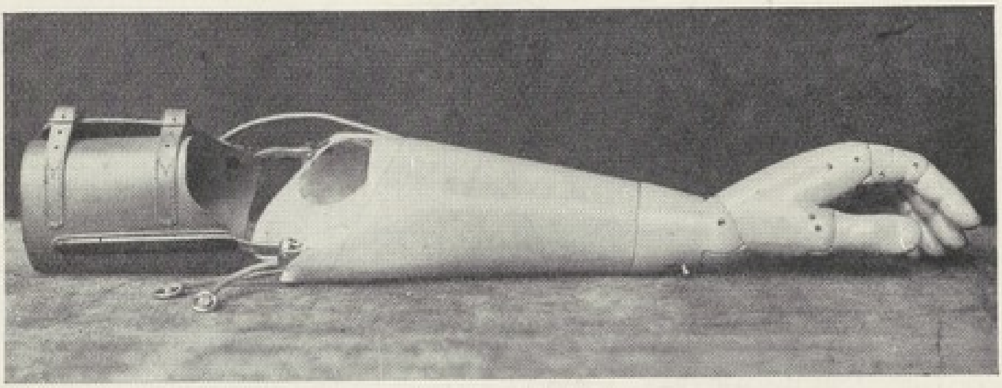


FIG. 96.—CARNES ARM FOR BELOW ELBOW AMPUTATION.
(From a photograph.)

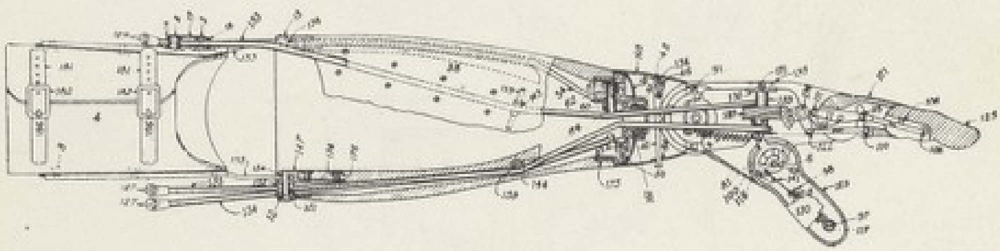


FIG. 97.—MECHANISM OF CARNES ARM FOR ABOVE ELBOW AMPUTATION.
(From a drawing.)

For the above illustrations I am indebted to the Carnes Artificial Limb Co., Kansas City, Mo., U.S.A.

This action does not only add to the natural appearance of the movement, but it enables the wearer to convey food to the mouth easily. The power to do this is not of much importance when there is one sound hand remaining, but in cases of loss of both hands it is of great value. As it is not desirable that elbow flexion should always be accompanied by hand supination, provision is made for cutting out this latter motion. This is done simply by fully flexing the forearm upon the upper arm.

The action of the fingers and thumb is one of simple flexion and extension. The fingers when closed are locked, so that they are much more resistant than those of hands which depend upon springs for resistance to extension. This is effected by mechanism

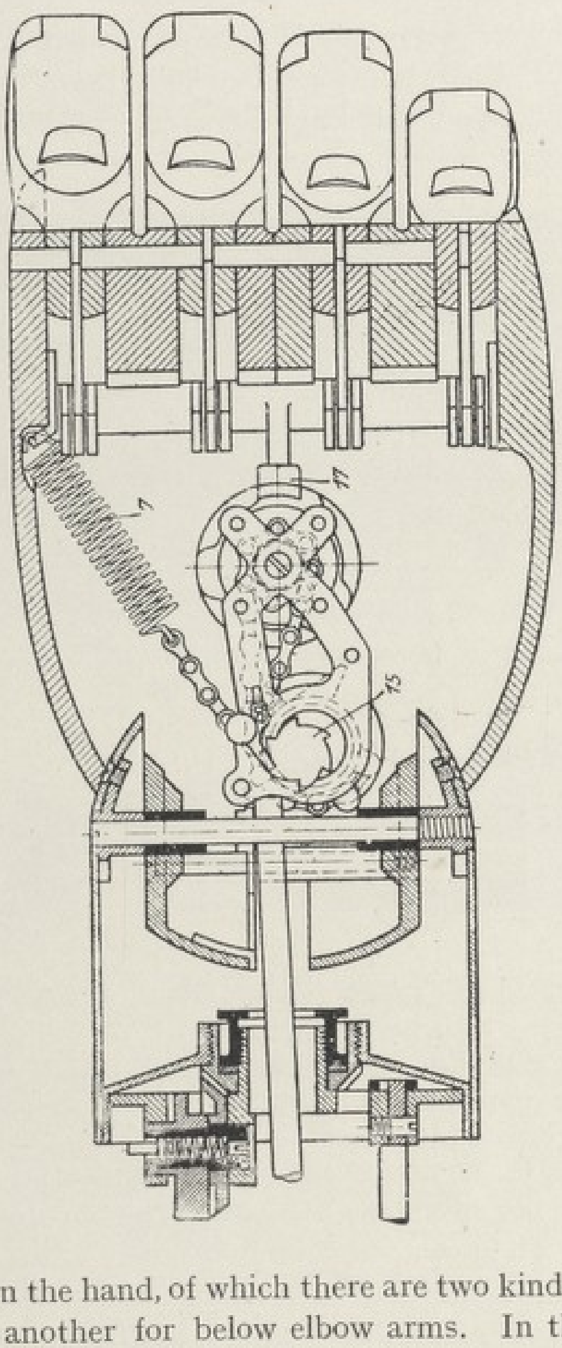


FIG. 98.—CARNES HAND FOR UPPER ARM STUMPS.

contained in the hand, of which there are two kinds, one for above elbow and another for below elbow arms. In the above elbow arm there is only one source of power available for the fingers, therefore the mechanism is so made that one pull opens the fingers and the repetition of the pull on the same thong closes them.

In the below elbow arm there are two sources of power available, as one is not wanted to flex the elbow. There are therefore two thongs, traction on one of which opens and on the other closes the fingers. The annexed illustrations show the mechanism, but

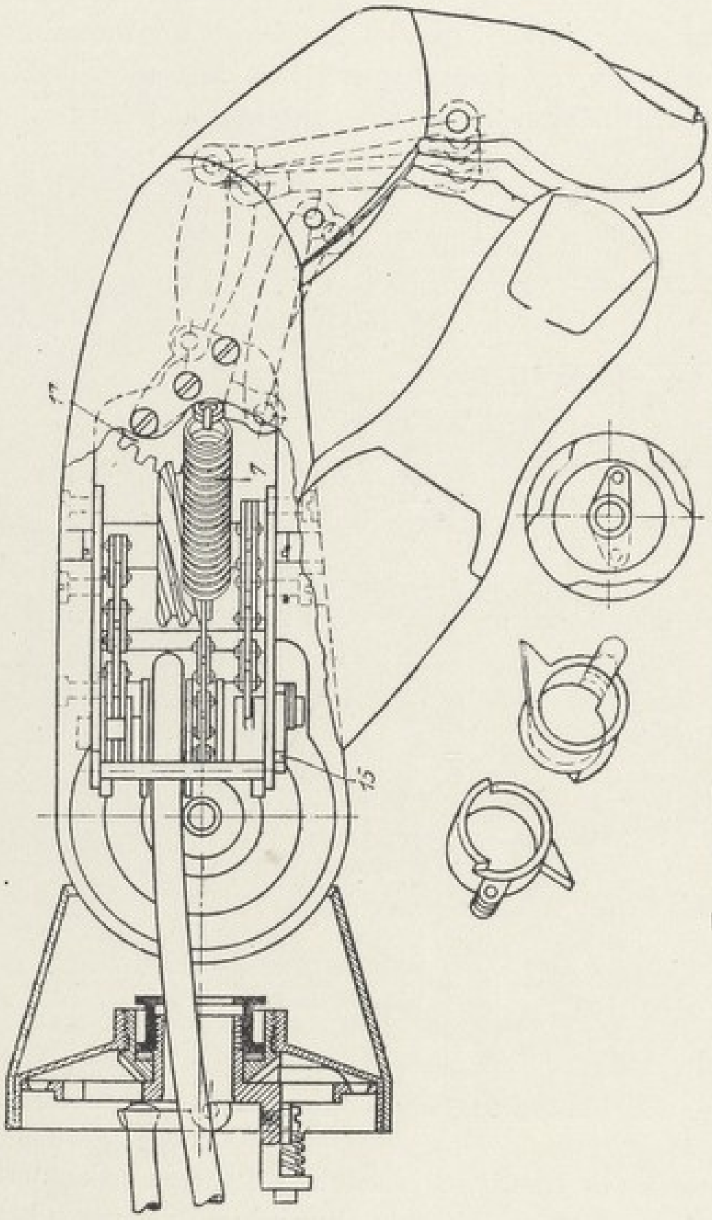


FIG. 99.—CARNES HAND FOR UPPER ARM STUMPS.

it is too elaborate for description here. It has been minutely described, however, by Barth and Schlesinger (see figs. 98 to 101).[1]

The Pringle-Kirk hand already referred to is used for heavy

[1] *Zeitschr. d. Ver. deutsch. Ingenieure*, 1916, 60, 1089, of which see abstract in the *Medical Supplement, Daily Review of the Foreign Press* I. 6, p. 155 *et seq*.

work. It is not a mechanical hand in the sense that it can be controlled by the muscles of the mutilated side, but it requires the aid of the sound hand to open and close the fingers. It has the advantage of a ball-and-socket joint at the wrist, which allows the hand to be fixed in various positions relatively to the fore-arm (see fig. 102). The fingers and thumb are movable at the metacarpo-phalangeal joints only, but are modelled in the position of semi-flexion at the interphalangeal joints.

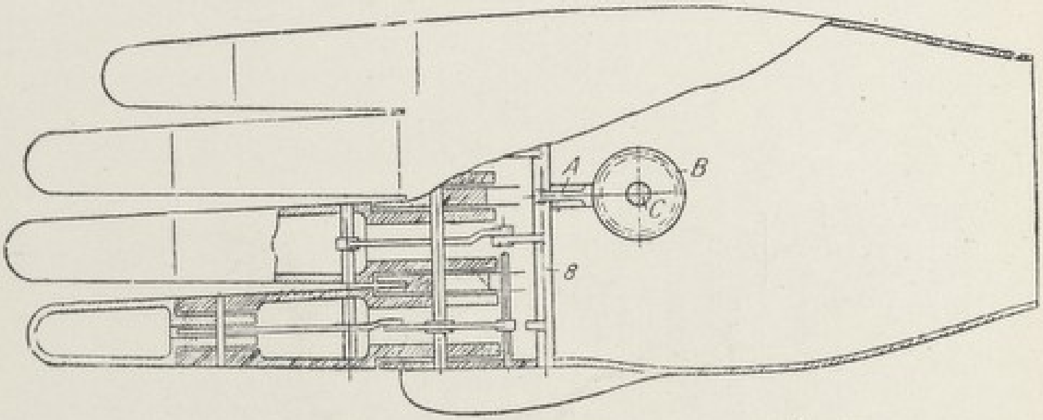


FIG. 100.—HAND OF CARNES ARM FOR FOREARM STUMPS.

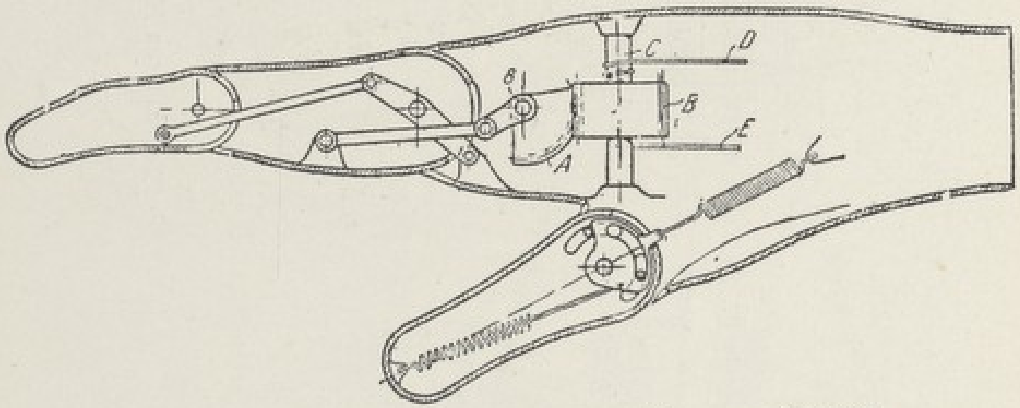


FIG. 101.—HAND OF CARNES ARM FOR FOREARM STUMPS.

In the Cauet hand, a French invention, the wrist and metacarpal part is made of aluminium alloy and of thin steel. Each digit consists of a dorsal shell of nickelled steel filled with cork, so that the flexor surfaces consist of the latter material. The grip of such a surface is less likely to slip than that of metal or wooden fingers. The fingers and thumb are movable at the metacarpo-phalangeal joints only, but are modelled in the position of semi-flexion at the interphalangeal joints. Closure is effected by means of a spring, and the grasp is opened by a Bowden cable worked by the shoulders or chest, and actuating the thumb and the index and middle fingers (see fig. 115).

In this hand the disadvantage of spring closure is obviated by a locking mechanism. By means of this, as soon as the fingers have closed upon an object and the extension cable is relaxed, the fingers are locked. The first effect of a pull upon the opening cable is to open the lock, and further effort pulls open the digits. With such a locking mechanism it is not necessary to employ very strong springs, and therefore the power required to open the fist can be reduced and fatigue avoided.

The Cauet hand can be rotated at the wrist by the help of the

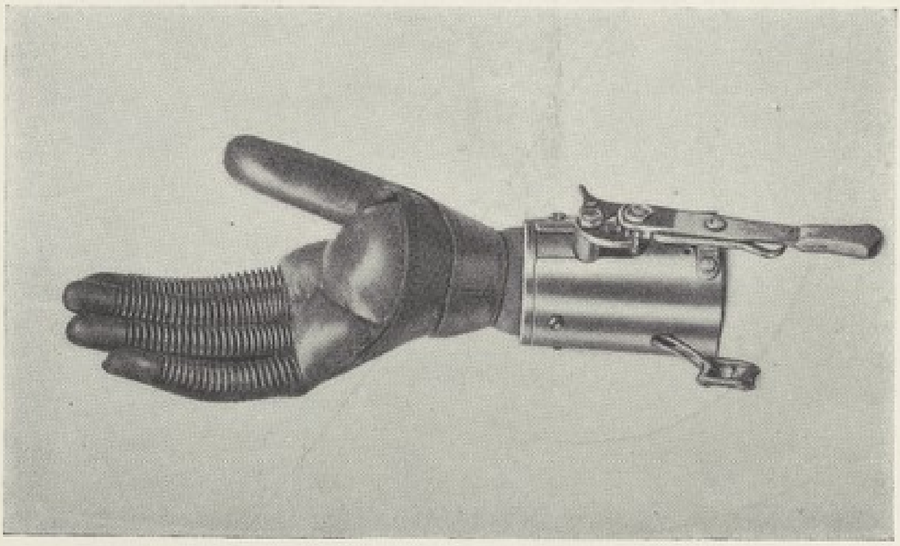


FIG. 102.—PRINGLE-KIRK HAND.

sound hand so as to fix it in various positions of pronation or supination. It is attached to the forearm by means of a spring snap catch, and appliances can be substituted for it.

The McKay hand is made of indiarubber with a wooden core, to which a duralumin plate carrying the pinion of a snap catch is fixed. The digits are strengthened by central stems of stout copper, which give stiffness to them, and at the same time allow of their being bent or straightened as desired. These stems can be easily removed and replaced in case of damage. The thumb is mounted on a hinge at a point corresponding to the metacarpo-phalangeal joint, and is kept in flexion-adduction by a strong spiral steel spring. A spring catch at the wrist, worked by the sound hand, enables the artificial hand to be rotated and fixed in any desired position of pronation or supination (see fig. 103). In the McKay arms the snap catch mechanism for the hand is not the same as that used for appliances. In the end of the forearm part of each McKay arm there are two snap catch sockets, one within the other. The outer and stronger is for appliances, and the inner one for the hand only.

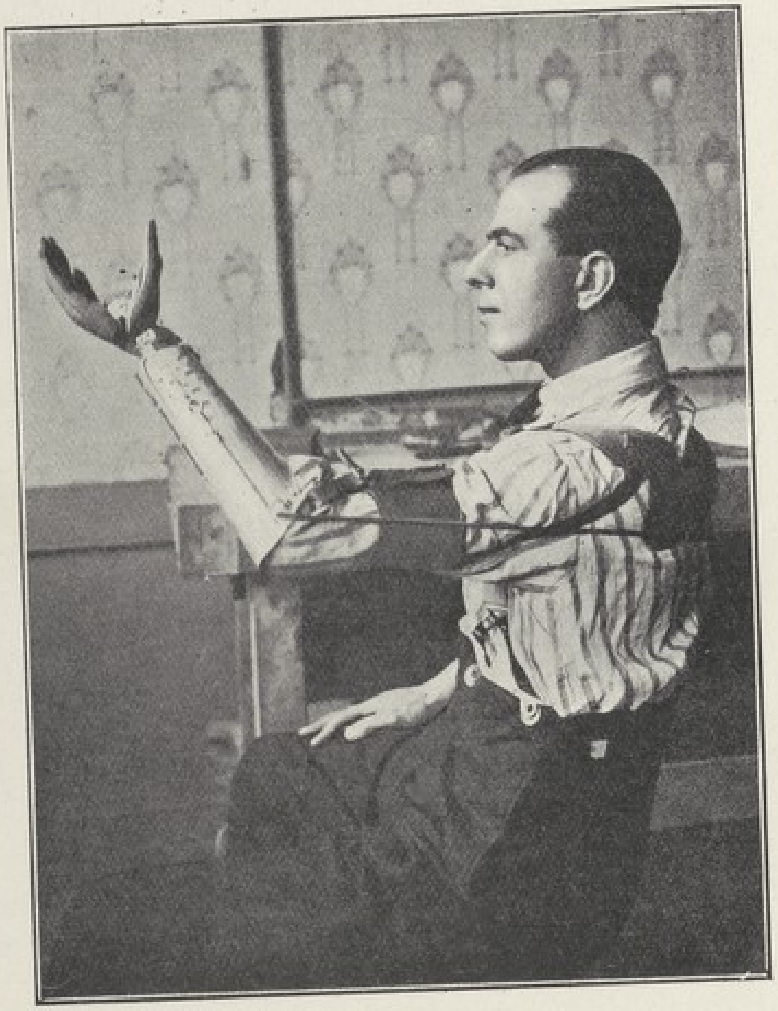


FIG. 103.—MCKAY HAND.

The McKay hand is necessarily somewhat heavy. A lighter hand on somewhat similar principles is the Blatchford hand with felt fingers (see fig. 112). This hand is made of wood, except the fingers, which are of felt with copper central stems which are adjustable, like those in the McKay hand. The wooden thumb is long, being hinged at a site nearer the imaginary carpo-metacarpal than the metacarpo-phalangeal joint. This is unsightly in the uncovered hand, but when a glove is worn the leather takes the place of the musculo-cutaneous web of the natural hand and masks the deformity. The thumb has the typical spring closure and active opening by a pull from the shoulder. This hand is not suited to hard work, but may be useful for light work and for appearance' sake. It is mostly fitted to arms for short stumps in which lightness is a great consideration.

The lightest artificial hand that has been supplied by the Ministry of Pensions is that made by Albert E. Evans, which weighs about 6 ounces. This is constructed of muslin and celluloid covered with leather. Although it is hollow throughout it is very strong; indeed, owing to the absence of grain, it is stronger than the ordinary types of wooden hand. The fingers are not articulated, the thumb is hinged, and is closed by a spring in the usual way. It is detachable by means of a keyhole catch. A light hook can be substituted for it. Such a very light hand is acceptable in cases in which from shortness of stump, paralysis, or other complications, only the lightest possible prosthesis can be worn. It may reasonably be urged that in such cases it is better to do without one altogether. There is, however, a very strong desire among amputees to conceal their mutilations as much as possible, and it is right and proper to meet their wishes in every possible way.

For long forearm stumps in which the power of pronation and supination is of good range and force, hands have been devised utilizing this movement to open and close the fingers, but the result appears to be poor and hardly worth seeking. It seems better to use the rotation power for its natural physiological function of adjusting the position and inclination of the hand, and to flex or extend the fingers by other means. The power of pronation and supination is of great value, and every care should be taken to preserve it and to avoid hampering its action by metal elbow-joints, or too long or stiff sockets, whenever these are avoidable.

It is to be noted, however, that often, even in long stumps, when passive rotation is easy and of full range, active volitional pronation is feeble and of restricted range.

Supposing that the pronator teres is normal, these conditions appear to be due to two chief causes: one is the absence of, or severe injury to, the pronator quadratus, which is the most effective agent in pronation; and the other is the loss of the triangular cartilage and of the normal lower radio-ulnar joint.

Electro-magnetic and pneumatic hands have been made and are described by Schlesinger ("Ersatzglieder," etc., Berlin, Julius Springer, 1919). These are brought into action by the intervention of the sound hand or by pressure on a button or bulb by other means. They do not appear to be of much practical value.

For cinematized stumps special prostheses have been devised for the two chief classes of motors—the tunnel and the club. It is obvious that, given one or more sources of power, the essential mechanism of a hand such as the Carnes could be operated by the

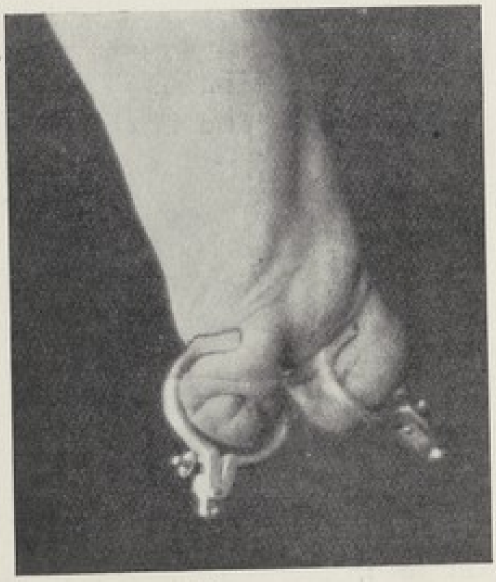


Fig. 104.

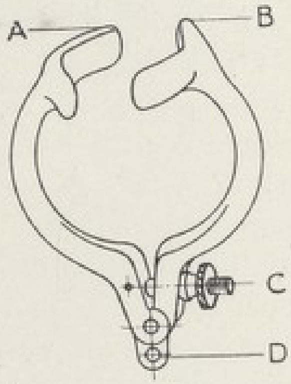


Fig. 105.

cords attached to the motors. Most of the cases are those of above elbow amputation. In these it is essential that the cords from the motors to the hand shall pass through or very close to the axis of the elbow-joint. If this is not done, it is obvious that the distance traversed by the cord between the artificial hand and the motor will vary with flexion or extension of the artificial elbow. The tension of the cords, therefore, would vary, and when they were slack the motors would act at a great disadvantage or even have no effect at all.

The prosthesis shown in figs. 106 to 109 was designed and made in the Experimental Workshop of the Ministry of Pensions, for club motors made by Mr. M. Fitzmaurice Kelly, as described by him (*vide supra*) and shown in fig. 104. The clamp by which the cord or cable is connected with the motor is shown in fig. 105. This form was devised to avoid the constriction and consequent congestion which the ring form was likely to cause. The two curved jaws of this clamp securely grip

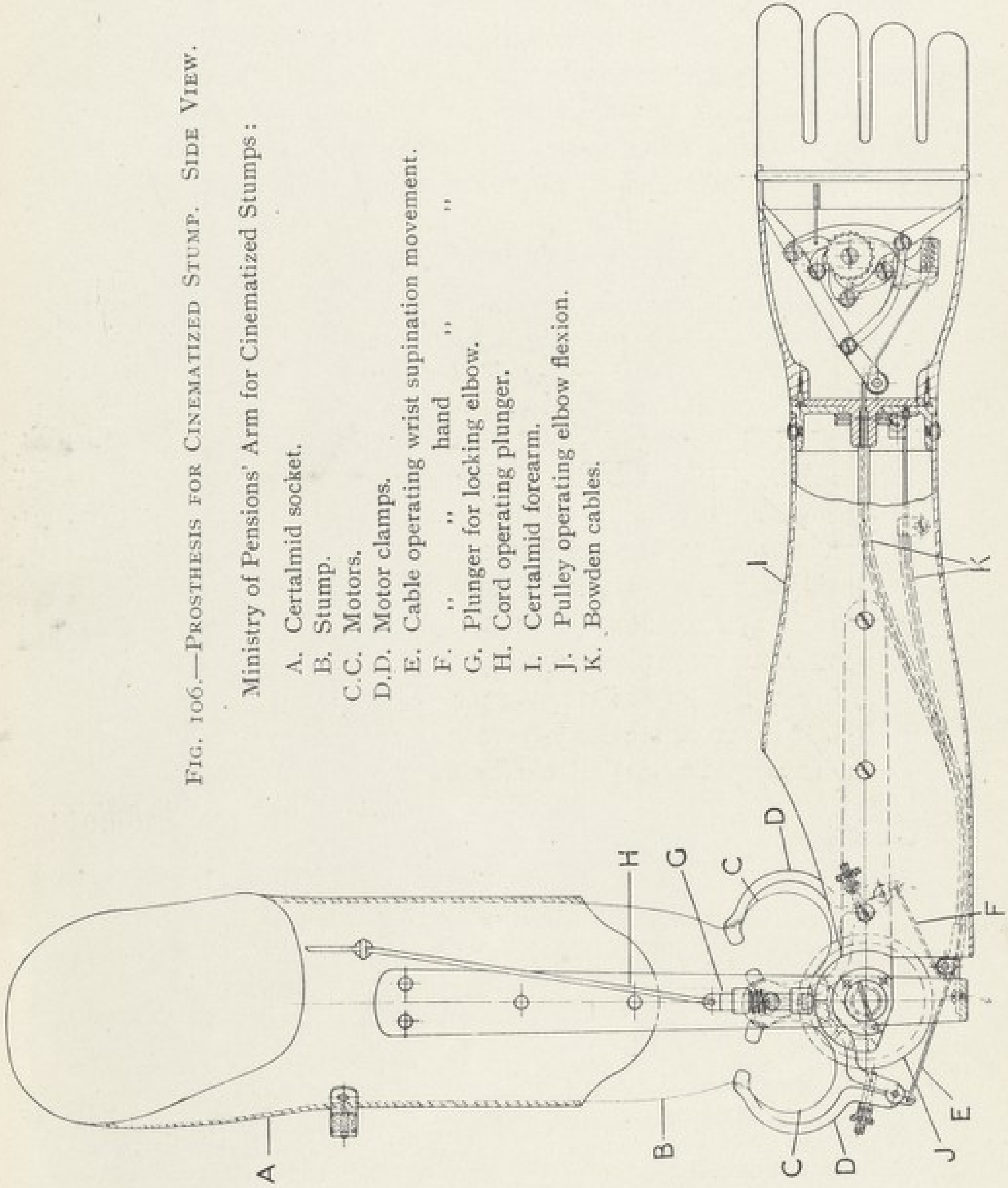


Fig. 106.—Prosthesis for Cinematized Stump. Side View.

Ministry of Pensions' Arm for Cinematized Stumps:

A. Certalmid socket.
B. Stump.
C.C. Motors.
D.D. Motor clamps.
E. Cable operating wrist supination movement.
F. " " hand " "
G. Plunger for locking elbow.
H. Cord operating plunger.
I. Certalmid forearm.
J. Pulley operating elbow flexion.
K. Bowden cables.

the neck of the motor above the nodule of bone, without constricting it. The biceps and brachialis motor is used to close the fingers and the triceps to supinate the hand at the wrist.

The finger mechanism, which for above elbow cases is placed in the forearm (thereby relieving the hand of its weight), in cases of below elbow amputation is placed in the hand. It is simple, strong, and light. When the fingers are closed upon an object

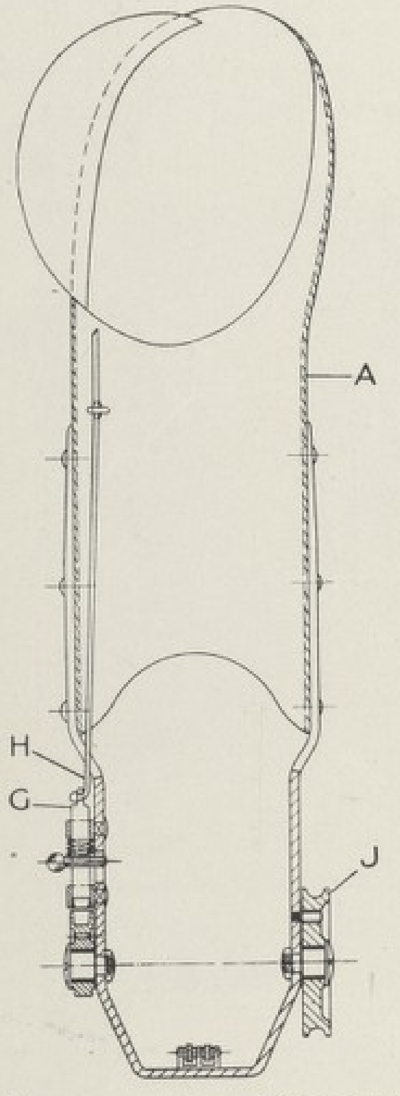


FIG. 107.—ANTERO-POSTERIOR VIEW OF FIG. 106 WHEN ELBOW IS FLEXED.

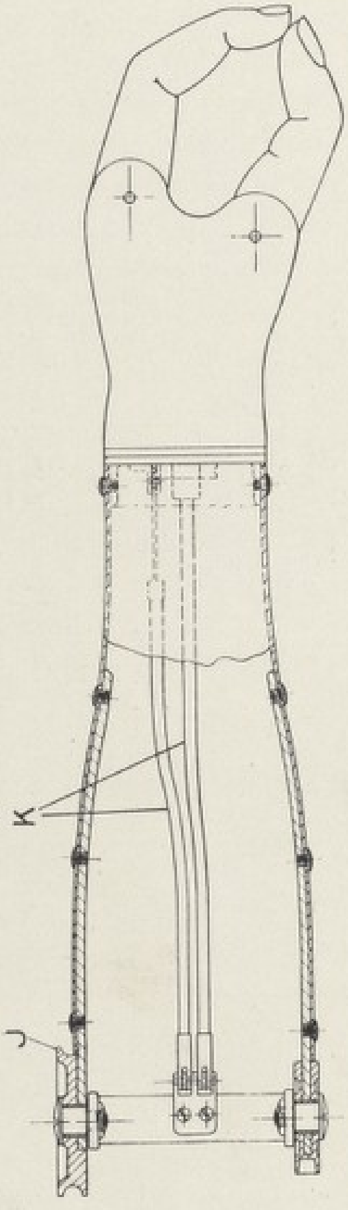


FIG. 108.—ANTERO-POSTERIOR VIEW OF FOREARM AND HAND OF PROSTHESIS FOR CINEMATIZED STUMP.

they are locked so that a pull upon the cable is necessary to relax the grip.

Fig. 109 shows the arm in wear. It is not intended for heavy manual work, for which the strength of the motors is insufficient, but could be adapted for any strength of motor, and by using a rod and shackle instead of the clamp, can be equally well worked by means of tunnel motors. Until the usefulness of this or of other special arms is fully established, the operations of cinematization of stumps cannot be recommended.

Arms and hands for one or two tunnel motors of the Sauerbruch type are described by Schlesinger in "Ersatzglieder."[1] It is easier to fit prostheses for these than for club motors, because the latter require more room when they contract, and

FIG. 109.

(especially the triceps motor) sometimes move in a direction at an angle with the long axis of the socket.

The simple Rohrmann arm and hand is designed for one biceps motor only, which is used to close the thumb and fingers together, opening being produced by the action of a spring. This arrangement is probably the best, provided the motor is not easily fatigued. The design and manufacture of prostheses for cinematized forearm stumps offer fewer difficulties.

[1] *Op cit.*, 420-423.

CHAPTER IX

THE BRITISH OFFICIAL ARM PROSTHESES

THE arms supplied by the Ministry of Pensions are divided into three classes:

1. Those for hard work: "Heavy workers' arms."
2. Those for light work: "Light workers' arms."
3. Those for ornament more than for use: "Light dress arms."

Although these "dress arms" are intended primarily merely to fill the sleeve and mask mutilation, all the prostheses in the category 3 are of some use. A light bag or despatch case can be carried upon the bent fingers, and when the elbow is bent and locked at a right angle an overcoat can be hung across the forearm and so carried.

It appears likely that the second class will disappear, as a type of ornamental arm is being evolved which is well suited for light work. The amputation region for which each arm is intended is indicated by a letter of the alphabet thus:

A. Through the shoulder-joint, or without useful stump.
B. Upper arm. Short stump.
C. Upper arm. Long stump.
D. Elbow-joint, or too high in forearm for usefulness.
E. Forearm. Short stump.
F. Forearm. Long stump.
G. Wrist-joint.

The combination of a letter indicating the region and a number indicating the purpose for which the arm is intended specify each arm; thus A 1 is a shoulder-joint arm for hard work, and E 3 is a light dress arm for a short forearm stump.

The average weights of the arms (including hands) supplied by the Ministry at the present time for the more common types of amputation are as follows:

	Workers' Arms.	*Dress Arms.*
For disarticulation at the shoulder	4 lb.	2 lb. 6 oz.
For amputation above elbow	3 lb.	2 lb.
For ,, below ,,	2 lb.	14 oz.

Arms for Shoulder Amputations.

Disarticulations at the shoulder-joint and amputations through the shaft of the humerus so high up as to leave no useful working stump are fitted with shoulder-joint prostheses.

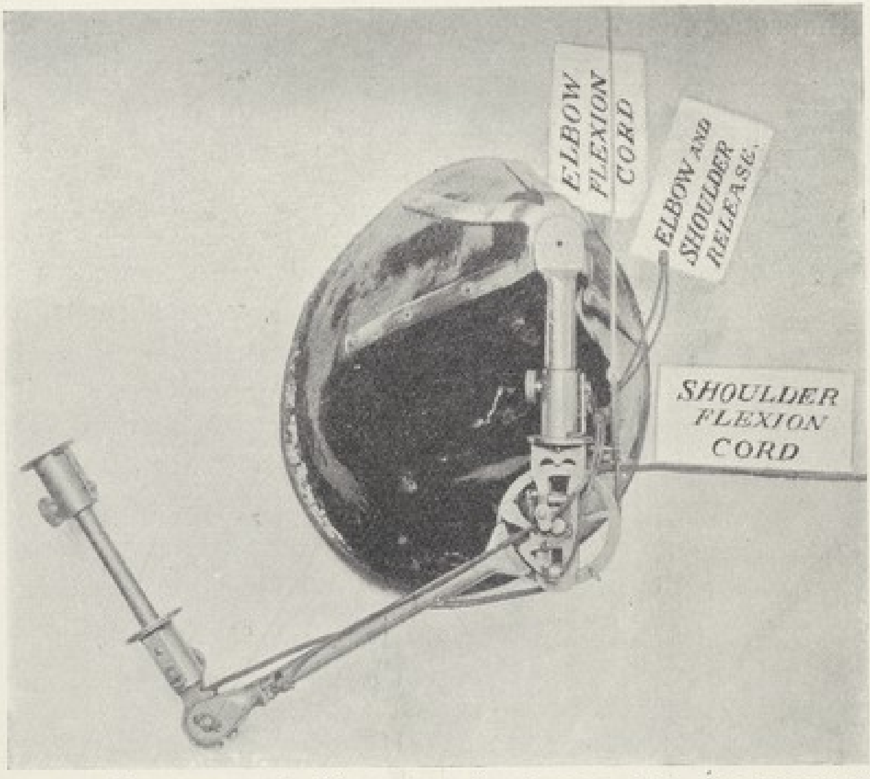


FIG. 110.—BLATCHFORD'S WORKING APPLIANCE FOR SHOULDER-JOINT AMPUTATION. APPLIANCE COMPLETE; FLEXED AT SHOULDER AND ELBOW.

In the early years of the Great War these were generally made without any joint at the shoulder. A stiff leather case, moulded on a plaster cast enclosed the front and back and upper surface of the shoulder, and was rigidly continuous with the upper arm piece of wood and other material. A rotation joint to enable the elbow and forearm to be fixed in various positions was sometimes inserted in the upper arm piece. The rest of the arm and hand was similar to those of upper arm prostheses. These arms were of limited usefulness, and experience showed that not many of them were worn.

The ornamental or dress types at present supplied by the Ministry of Pensions all have joints at the shoulder, which allow of flexion and extension and a few degrees of abduction, so as to allow the limb to swing and thus appear the more natural.

A useful worker's arm for shoulder-joint amputations, etc., is the A 1, made by Anderson and Whitelaw, of leather and steel. This has no movable shoulder-joint. Although appliances and an artificial hand can be used at the end of the forearm, for heavy work the elbow-joint and all parts below it are detached not far below the shoulder, and a hook or other tool is affixed directly to the socket. In digging, using a wheelbarrow or a sledge-hammer or pickaxe (all of which occupations are practised at the Arm Training Schools of the Ministry of Pensions), very little actual force is exerted through the prosthesis. The latter is used as a point of support and fulcrum for the tool, which is energized and directed by the sound member.

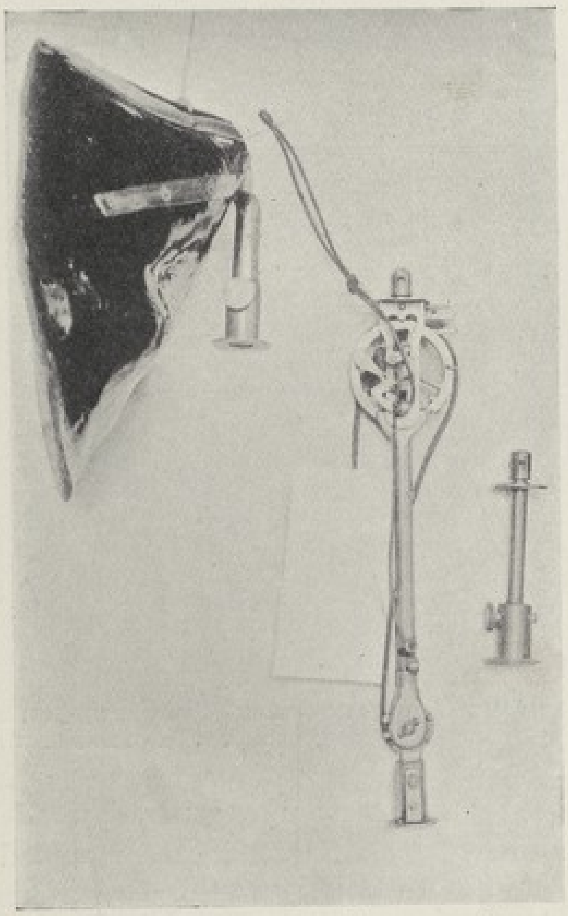


FIG. 111.—BLATCHFORD'S SHOULDER APPLIANCE WITH THE ARM AND FOREARM PARTS DETACHED AT THE SNAP CATCHES.

An A 1 worker's arm for shoulder-joint amputations, which is officially described as a working appliance, is made by C. A. Blatchford. This differs from other shoulder arms in that it has a joint just below the shoulder which is controlled by the action of trunk and shoulder muscles, as well as a joint of the usual type at the elbow. The upper arm part can be detached just below the shoulder-joint, and the forearm part just below the elbow. This is a skeleton arm, and makes no pretence to imitate nature in appearance, but ornamental arm and forearm pieces can be added to it (see figs. 110 and 111). This appliance is suitable for men doing certain kinds of work, but for the majority of shoulder cases a more simple prosthesis is preferable.

Another type of worker's shoulder-joint arm is the A 1 arm made by P. M. McKay. The shoulder cap, arm, and forearm pieces of this prosthesis are made of duralumin, strengthened with steel and with steel joints. The elbow control and lock do not differ in principles from those already described. The rubber hand with copper cores to the fingers has already been referred to.

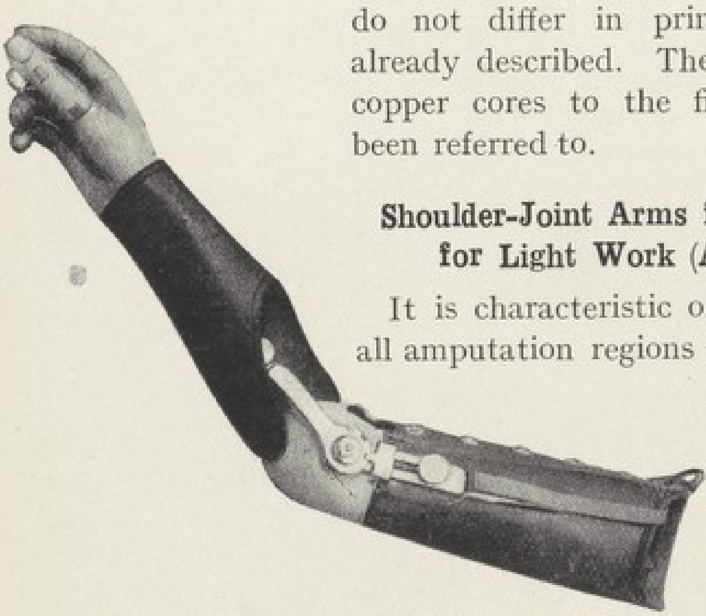


FIG. 112.—BLATCHFORD'S ABOVE ELBOW ARM, WITH STIRRUP ATTACHMENT.

Shoulder-Joint Arms for Ornament and for Light Work (A 2 and A 3).

It is characteristic of all light arms for all amputation regions that the forearm or the forearm and elbow are not made detachable, as is the case in the workers' arms. In some patterns for lightness' sake the hand is made a fixture, thus saving the weight of two metal wrist plates and screws, but it is more usual to make the hand detachable so that appliances may be used; but these prostheses are primarily intended merely to fill the sleeve and mask mutilation.

The light dress arm is quite strong enough to bear the strain of appliances for clerical work and for draughtsmen and such-like, and therefore it is generally made with a detachable hand.

The light dress shoulder-joint arm A 3 of Anderson and Whitelaw of the latest pattern is shown in fig. 113. It is made of celluloid and muslin, and the elbow is flexed and locked and unlocked by movements of the shoulders, as already explained on p. 103 in describing the older pattern.

FIG. 113.—A 3 ARM.

Another useful shoulder-joint arm, which is classed officially as A 3, but is suitable also for light work, is that made by H. Steeper, Ltd., who are makers of the Cauet hand in Great Britain. This hand has already been described (see figs. 115 and 116).

The A 2 arm of Ernst is a dress arm which is distinguished as having a ball-bearing shoulder-joint. It has a moulded leather shoulder cap. The elbow can be locked in any one of eight positions, but there is no "automatic" elbow control. The fore-arm is made of blocked leather. The wooden hand has the usual spring thumb. This arm has a rotation joint just above the elbow, by means of which the forearm and elbow can be

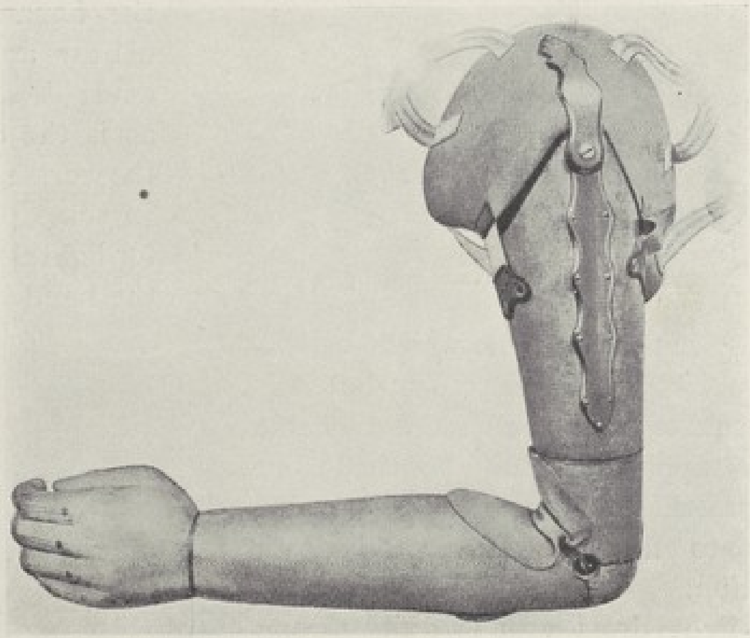


FIG. 114.—F. G. ERNST'S SHOULDER-JOINT ARM.

turned outwards or inwards across the front of the body, as mentioned on p. 123 (see fig. 114).

The worker's shoulder-joint arm A 1 is the type most suited for stumps of the upper arm of 2 inches or less in length, measuring from the anterior fold of the axilla. There are, however, a few persons whose stumps and whose wills are so strong that they will make good use of a B arm with a stump under that length, but the poor leverage afforded by the short stump for moving the socket makes the use of a below shoulder worker's arm in such cases very fatiguing. Light dress arms may be fitted to stumps as short as 1 inch below the axilla.

B Arms.—For short stumps over 2 inches in length (measured

Fig. 115.—Cauet Arm and Hand, showing Opening of Fingers.

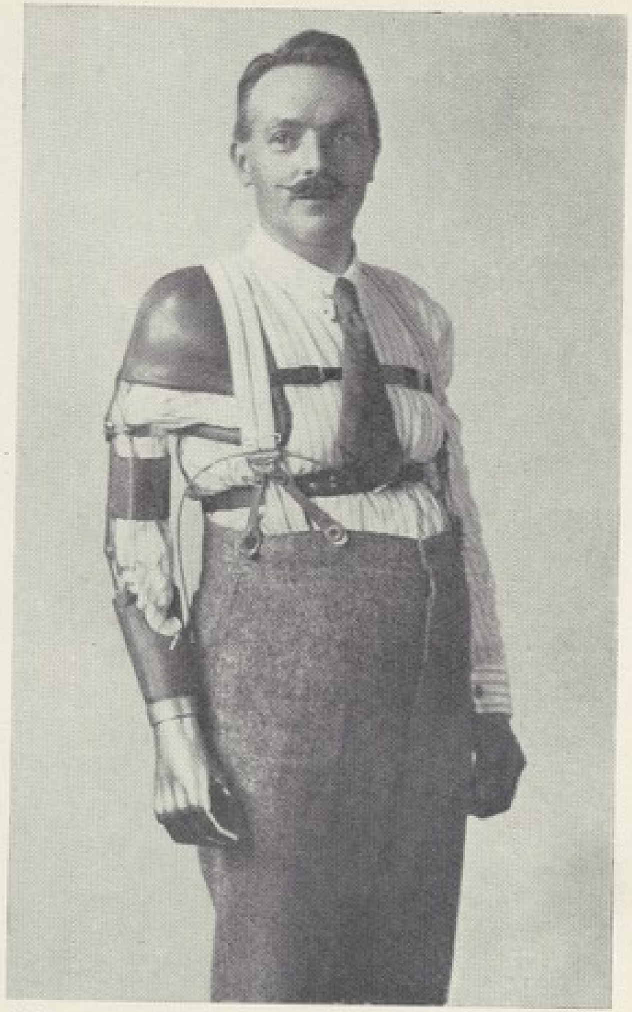


Fig. 116.—Cauet Arm and Hand for Disarticulation of the Shoulder.

[To face p. 126.

from the axillary fold) there are a number of useful arms. The types that have been most used are, for workers (B 1), those made by Anderson and Whitelaw, Blatchford, Cory and Grundy (the Adams arm), McKay, and Pringle-Kirk.

The workers' B and C arms generally have detachable forearms, so that appliances may be used close to the stump, avoiding the leverage of the artificial forearm.

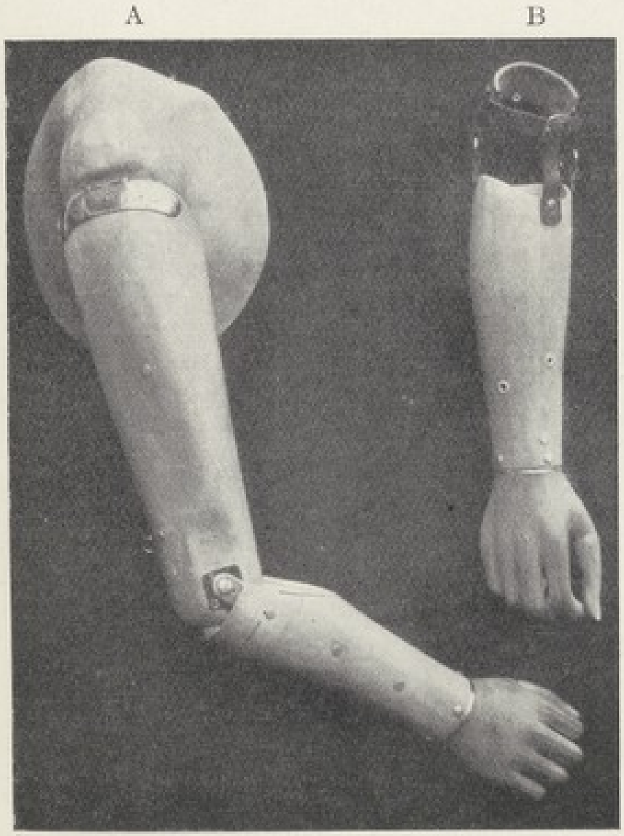


FIG. 117.—A, CORY AND GRUNDY'S LIGHT ARM FOR DISARTICULATION OF THE SHOULDER, WITH LIMITED ABDUCTION JOINT. B, LIGHT ARM FOR FOREARM AMPUTATION.

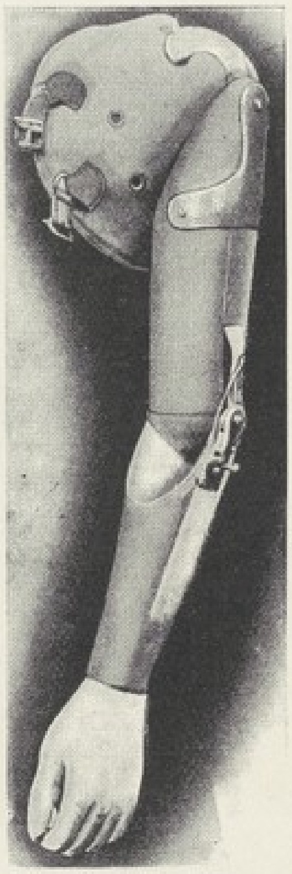


FIG. 118.—LIGHT DRESS A 3 ARM, MADE BY ANDERSON AND WHITELAW, FOR AMPUTATION AT THE SHOULDER.

For this purpose the stirrup appliance of Blatchford is very useful. As shown in the illustrations, the artificial forearm and hand is attached by a snap catch just below the elbow to a U-shaped piece bearing a socket. This U-shaped piece is controlled by the usual mechanism, and can be flexed and locked in various positions. For work the forearm is removed at the snap socket, and any appliance can be inserted in its place (see figs. 123 and 124).

The Anderson and Whitelaw arms have leather sockets strengthened with steel plates. The sockets for B arms are made of stiff moulded leather, but those for the longer C stumps are made with an opening along the front, which is closed by means of straps and buckles, so that the socket may be adjusted to the stump, at any rate in its upper two-thirds.

FIG. 119.—BLATCHFORD'S B I ARM. The anvil shown weighs 58 pounds. This is a test of the efficiency of the harness.

The Blatchford arm is the same for B as for C stumps. It also has a moulded leather socket, close to the end of which appliances may be fitted when the elbow-joint and forearm are detached (see fig. 119).

The Cory and Grundy working arm B I and C I is of the Adams pattern, which is made entirely of metal, the arm socket, forearm and much of the fittings being of duralumin. The hand is detachable, as is the forearm part, just below the elbow by snap catches. The elbow-joint and lock are both very strong, and the arm is very suitable for hard work (see figs. 121, 127 and 128).

The McKay worker's arm is the same for B and for C stumps. Like the same maker's shoulder-joint arm, it is made chiefly of duralumin strengthened with steel. This arm is much liked by amputees, and large numbers have been supplied by the Ministry (see figs. 122, 125 and 126).

The Pringle-Kirk arm is the same for B I and C I. It has a moulded leather socket reinforced with steel ribs, and an elbow-joint specially designed to allow complete flexion, and an elbow

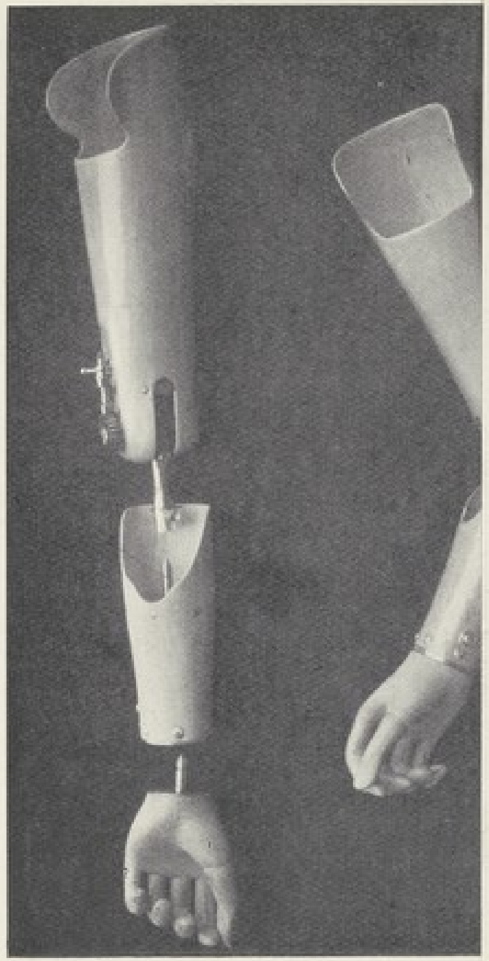


FIG. 120.—CORY AND GRUNDY'S WO[RK AND]
DRESS ARMS WITH "CERTALMID"
AND FOREARM PARTS.

CORRIGENDUM.

Page 128, line 11 from bottom, *after* 121, *add* 122.
" " " 4 " " *omit* 122.

FIG. 121.—ADAMS ARM, B 1 and C 1.
(Cory and Grundy, Ltd.)

[*To face p.* 128.

The Anderson and Whitelaw arms have leather sockets strengthened with steel plates. The sockets for B arms are made of stiff moulded leather, but those for the longer C stumps are made with an opening along the front, which is closed by means of straps and buckles, so that the socket may be adjusted to the stump, at any rate in its upper two-thirds.

The Blatchford arm is the same for B as for C stumps. It also has a moulded leather socket, close to the end of which appliances may be fitted when the elbow-joint and forearm are detached (see fig. 110).

FIG. 119.—BLATCHFORD'S B 1 ARM. The anvil shown weighs 58 pounds. This is a test of the efficiency of the harness.

The elbow-joint and lock are both very strong, and the arm is very suitable for hard work (see figs. 121, 127 and 128).

The McKay worker's arm is the same for B and for C stumps Like the same maker's shoulder-joint arm, it is made chiefly of duralumin strengthened with steel. This arm is much liked by amputees, and large numbers have been supplied by the Ministry (see figs. 122, 125 and 126).

The Pringle-Kirk arm is the same for B 1 and C 1. It has a moulded leather socket reinforced with steel ribs, and an elbow-joint specially designed to allow complete flexion, and an elbow

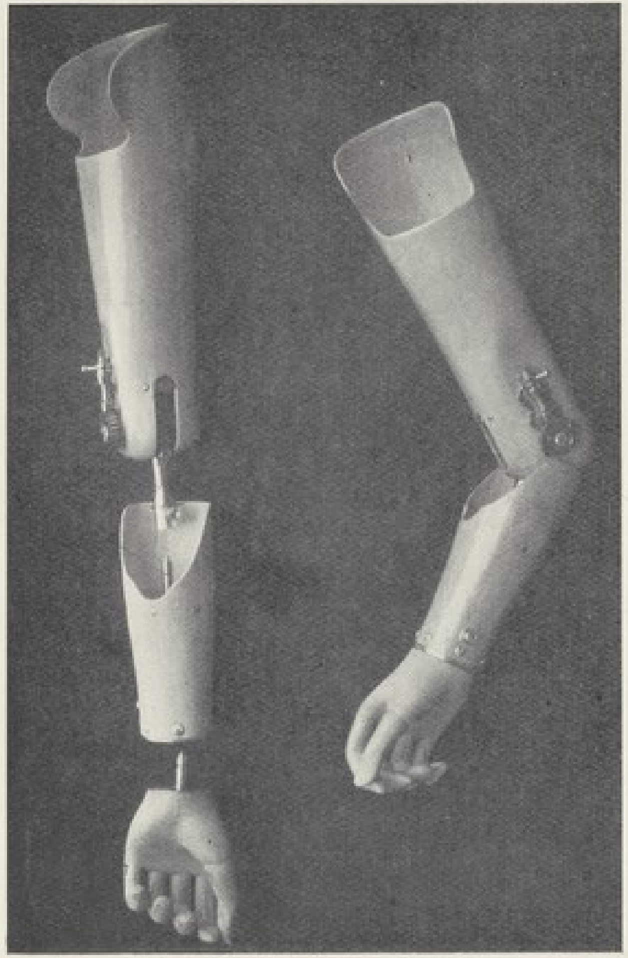


FIG. 120.—CORY AND GRUNDY'S WORKING AND DRESS ARMS WITH "CERTALMID" SOCKETS AND FOREARM PARTS.

FIG. 121.—ADAMS ARM, B 1 and C 1.
(Cory and Grundy, Ltd.)

[To face p. 128.

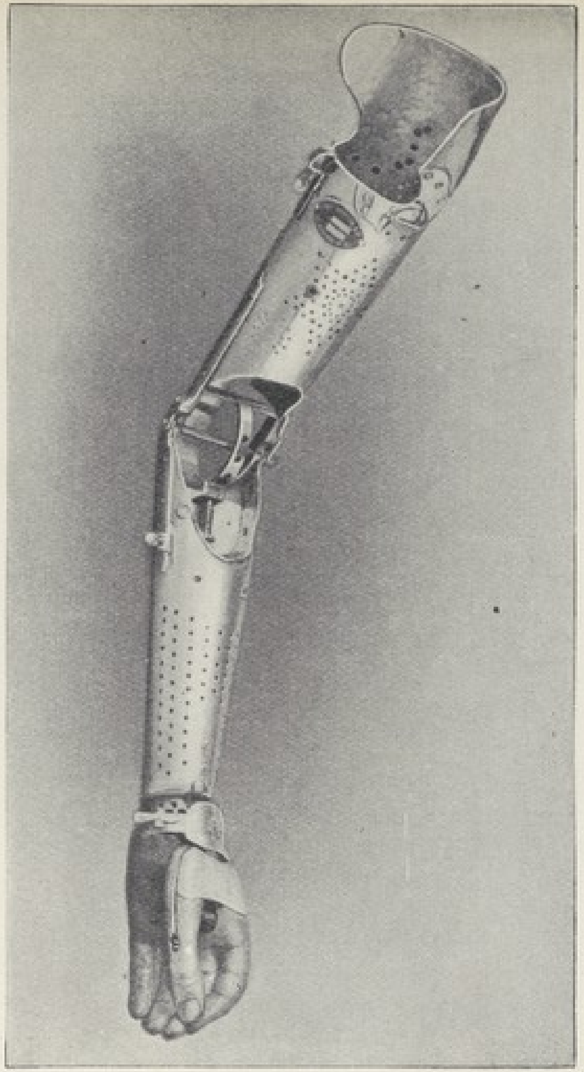


Fig. 125.—Mackay Workers' Arm with Rubber Hand. B 1 and C 1.

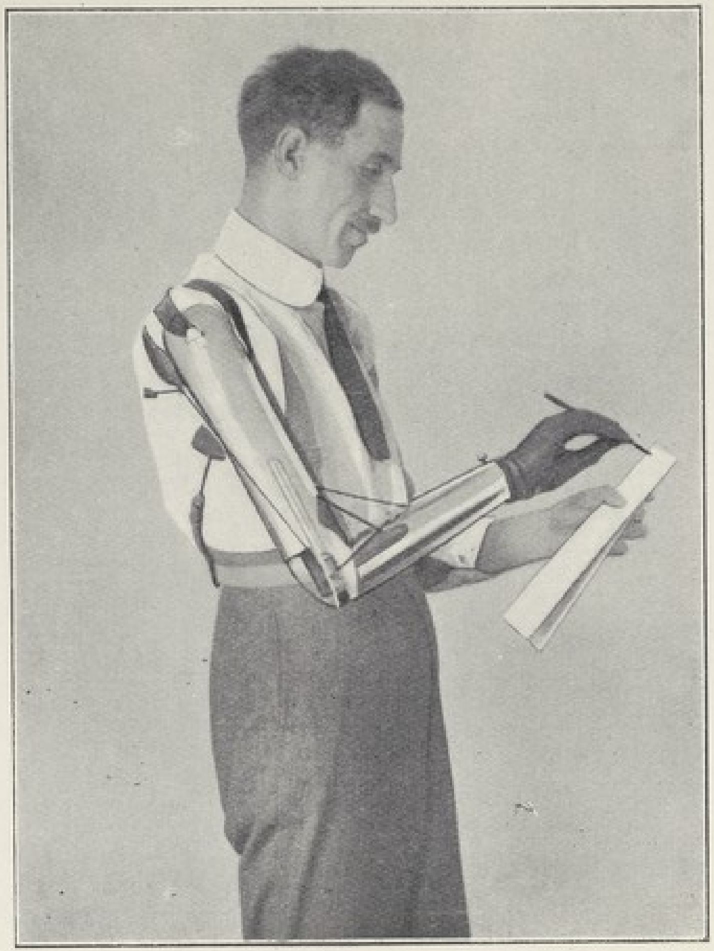


Fig. 126.—Mackay Workers' Arm in use. B 1 and C 1. [To face p. 129.

lock. Unlike most workers' B and C arms, the forearm cannot be removed, or appliances used at the elbow or wrist (see fig. 129).

The outstanding feature of this arm is the hand, which has been already described.

The arms in category D are for amputations through or so close above the elbow-joint that there is no room for a joint having a transverse bolt. They are also needed for amputations 3 or 4 inches below the elbow, which afford no practicable stump.

All these stumps are bulbous in form, so that if a rigid socket is made to fit the upper part of the stump, the enlarged lower end could not be thrust down into it. The socket must therefore be made adjustable, with an opening all down the front, to allow

NOTE.

Page 129, Fig. 122, legend *should read*—
"Adams Workers Arms" (Cory and Grundy), *not* "Mackay's Arms."

FIG. 122.—MCKAY ARMS.

of the insertion of the bulbous end, the upper parts being afterwards drawn together by eyelets or hooks and lace, or straps and buckles. The same difficulty is met with, and is similarly surmounted, in cases of amputation through the knee-joint and of Syme's amputation.

The lower end of the stump is enclosed, often in soft leather, and the artificial joints are situated one on each side at a level above the end of the stump, and corresponding to the axis of movement in the natural joint—that is to say, opposite the epicondyle and the epitrochlea. This arrangement gives a satisfactory appearance as long as the elbow is extended, but when it is flexed the end of the humerus in its socket projects below the level of the forearm, and the result is unsightly. It is to minimize this

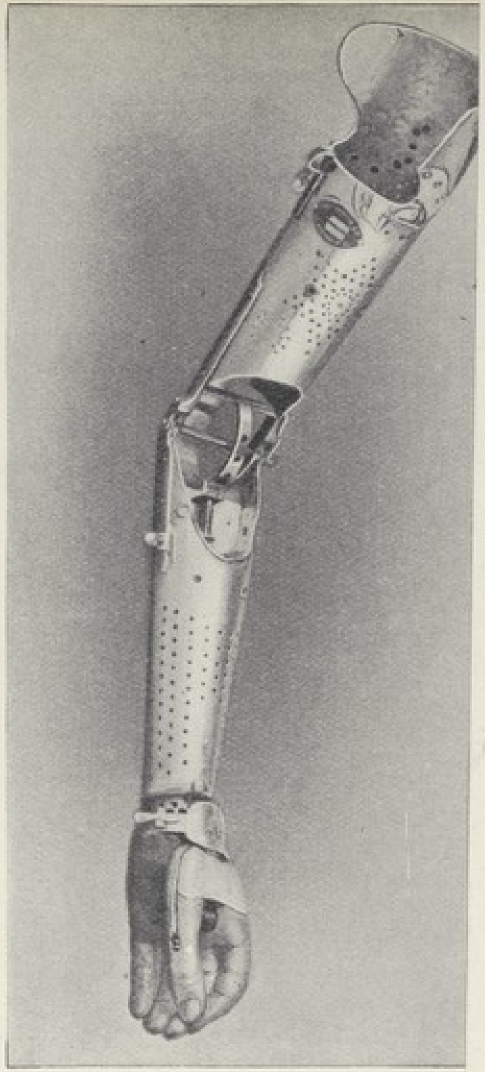


Fig. 125.—Mackay Workers' Arm
Rubber Hand. B 1 and C 1.

—Mackay Workers' Arm in use.
B 1 and C 1.

[To face p. 129.

lock. Unlike most workers' B and C arms, the forearm cannot be removed, or appliances used at the elbow or wrist (see fig. 129).

The outstanding feature of this arm is the hand, which has been already described.

The arms in category D are for amputations through or so close above the elbow-joint that there is no room for a joint having a transverse bolt. They are also needed for amputations 3 or 4 inches below the elbow, which afford no practicable stump.

All these stumps are bulbous in form, so that if a rigid socket is made to fit the upper part of the stump, the enlarged lower end could not be thrust down into it. The socket must therefore be made adjustable, with an opening all down the front, to allow

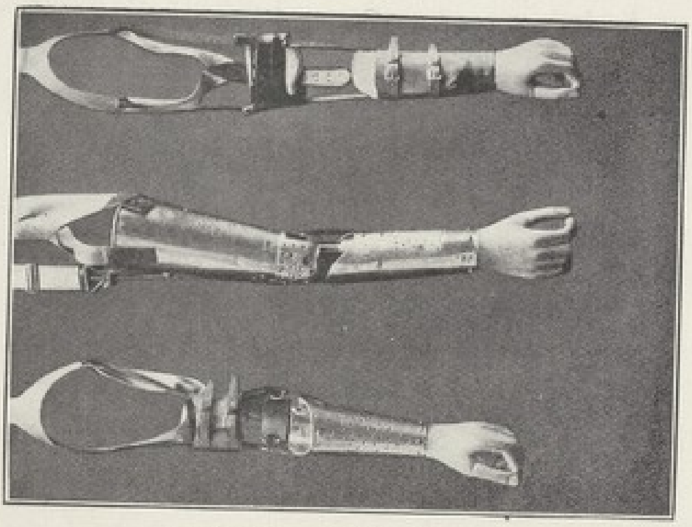


FIG. 122.—MCKAY ARMS.

of the insertion of the bulbous end, the upper parts being afterwards drawn together by eyelets or hooks and lace, or straps and buckles. The same difficulty is met with, and is similarly surmounted, in cases of amputation through the knee-joint and of Syme's amputation.

The lower end of the stump is enclosed, often in soft leather, and the artificial joints are situated one on each side at a level above the end of the stump, and corresponding to the axis of movement in the natural joint—that is to say, opposite the epicondyle and the epitrochlea. This arrangement gives a satisfactory appearance as long as the elbow is extended, but when it is flexed the end of the humerus in its socket projects below the level of the forearm, and the result is unsightly. It is to minimize this projection that the end of the stump is often enclosed in thin, soft leather, instead of in a thick socket. This projection also prevents the wearer from laying the forearm flat upon a table, etc., as mentioned in the section on stumps (p. 46).

It would be, of course, easy to ignore the position of the natural joint, and to fit the joint as in a C arm; but the dispro-

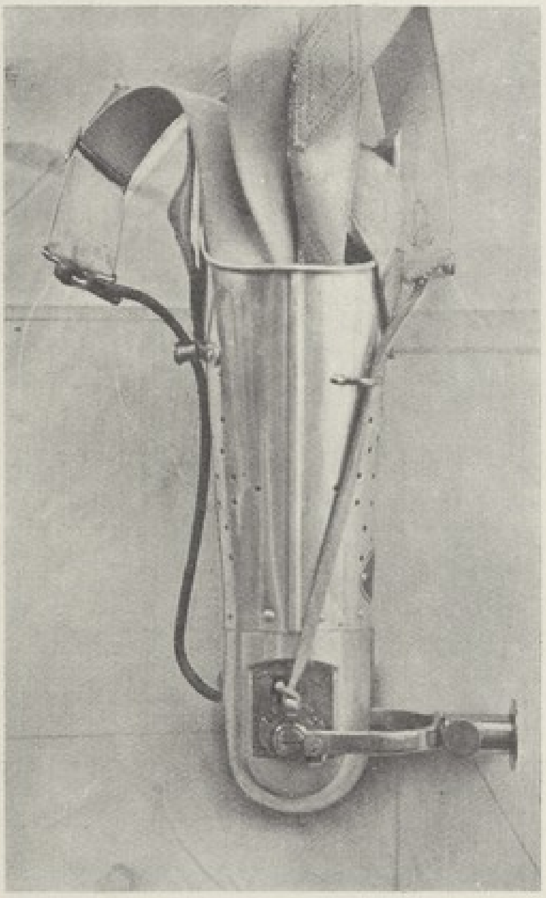


FIG. 123.—SIDE VIEW OF BLATCHFORD'S STIRRUP APPLIANCE WITH SNAP CATCH, FITTED TO A DURALUMIN SOCKET WITH ELBOW LOCK, ETC.

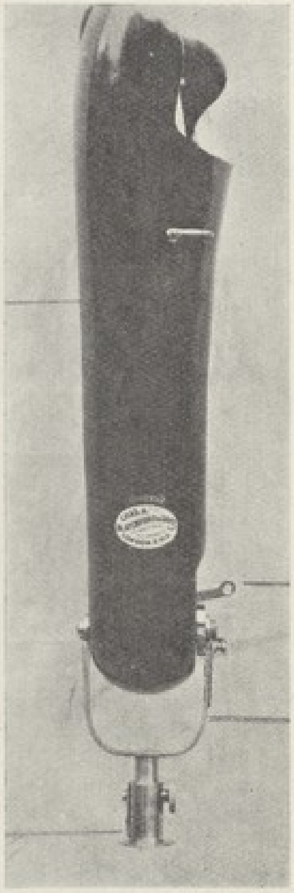


FIG. 124.—FRONT VIEW OF BLATCHFORD'S STIRRUP APPLIANCE FITTED TO A LEATHER SOCKET.

portionately short forearm is then very unsightly, especially when the forearm is in flexion. The D type of arm is also fitted to forearm stumps which are so short that they cannot carry any socket.

The Blatchford D 1 arm with stirrup fitting and detachable forearm is very suitable for such cases. In this the lower end of the stump is encased in buckskin, there is " automatic " elbow flexion, and a lock. Other makers construct the socket of leather or of aluminium alloy with a detachable forearm.

D 2 and D 3 arms are constructed on similar principles, but the forearm portion is not made detachable.

Forearm stumps, in which not more than 2 or 3 inches of the ulna remain (according as the development of muscular and adipose tissue is less or more), offer no stumps whatsoever for

FIG. 127. FIG. 128.

Fig. 127 shows the above elbow Adams Arm being used with a sledge-hammer, and Fig. 128 shows it used with rake and spade.

the attachment of a socket. Such stumps must be fitted generally with D type arms. Even if containing up to 6 inches of ulna, the stump is a poor one. This fact is recognized by the Ministry of Pensions, which assesses the pension for such a stump at 10 per cent. higher than for those of greater length. To get a hold on such a stump, the socket has to be carried well up in front of it, but on attempting to bend the elbow to a right angle, the tendon of the biceps and the remains of the forearm muscles bulge out in front of the joint, and either prevent the performance of the movement or else push the socket downwards so as to favour the escape of the stump from it.

This movement downwards is checked by the side steels, and by the grip of the upper arm corset above the condyles of the humerus.

If this latter is effective, the socket cannot descend, but at the same time the elbow cannot be bent to a right angle because of the muscles in front of the joint. Thus a block occurs and

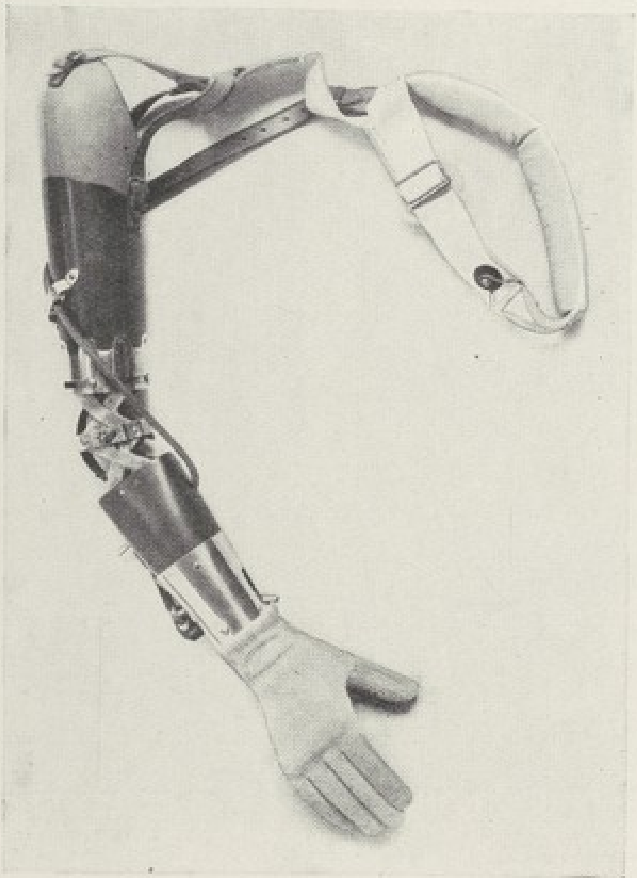


FIG. 129.—PRINGLE-KIRK ARM AND HAND.

the movement is arrested. The only practical way of getting over this difficulty is to cut away the top of the socket in front sufficiently, and to fit it to the stump as accurately as possible, so as to minimize the play between them and prevent angular movement (see illustration, etc., p. 88). At the same time the centres of the artificial elbow-joint should be placed rather in front of the axis of movement of the natural joint, in order to reduce the radius of flexion and the consequent excursion upwards of the front of the top of the socket. An attempt has been made in the Blatchford E 1 arm to allow the upper end of the socket to tilt forwards when the elbow is bent, and so give more room in front of the elbow. If, however, the socket fits as closely as it should do, any effective movement of this sort is impossible. These very short stumps, which tend to slip out of the socket whenever an attempt is made to flex the elbow of the prosthesis by their means, are best fitted with a "mechanically assisted" elbow-joint. This consists of a flexion mechanism worked by the shoulder muscles, as in an above elbow arm, with this difference, that owing to the presence of the natural elbow the mechanism has to be external. The joint is flexed, locked, and unlocked by muscular actions precisely similar to those used for the upper arm stump. Even for short stumps which do not slip out of the socket this "mechanical assistance" is recommended, because repeated efforts to flex the prosthesis by means of the stump alone quickly cause great fatigue. In all workers' arms for short forearm amputations the socket ends close to the end of the stump, and the rest of the forearm and the hand are detachable, and appliances are fitted close to the end of the socket in order to reduce the leverage.

The annexed figure shows how an arm amputee has devised a means of employing a short forearm stump ($3\frac{1}{2}$ inches long measured from the tip of the olecranon), which had to be fitted with a prosthesis as for a through elbow amputation. The stump of the forearm was thus of no use, and often was in the way. By attaching a cord to the soft leather covering at the end of the socket and connecting it with the fingers of a mechanical hand, Mr. H. Mills, of Rochdale (late Lancashire Fusiliers), provided for himself a useful grasping organ. It is obvious that the same cord could be attached to an appliance such as the split hook (see fig 130).

The elbow of the prosthesis is flexed as usual by shoulder action.

The illustration shows the stump and the cord in the two positions of extension and flexion. This device promises to be of much value for short or otherwise useless forearm stumps.

Even in light dress arms for very short stumps it is often advisable to fit a forearm shorter than natural, and mask the disproportion by shortening the coat sleeve accordingly.

For both short and long forearm stumps, the simple Williams arm, which is classed as E, F, and G 1, 2, and 3, often gives satisfaction. The peculiarity of this arm lies in the simplicity of its attachment. There is no harness or strap round the chest or shoulders, but only two lacing pieces of pliable leather stitched to the socket at each side by their lower edges, and gripping the

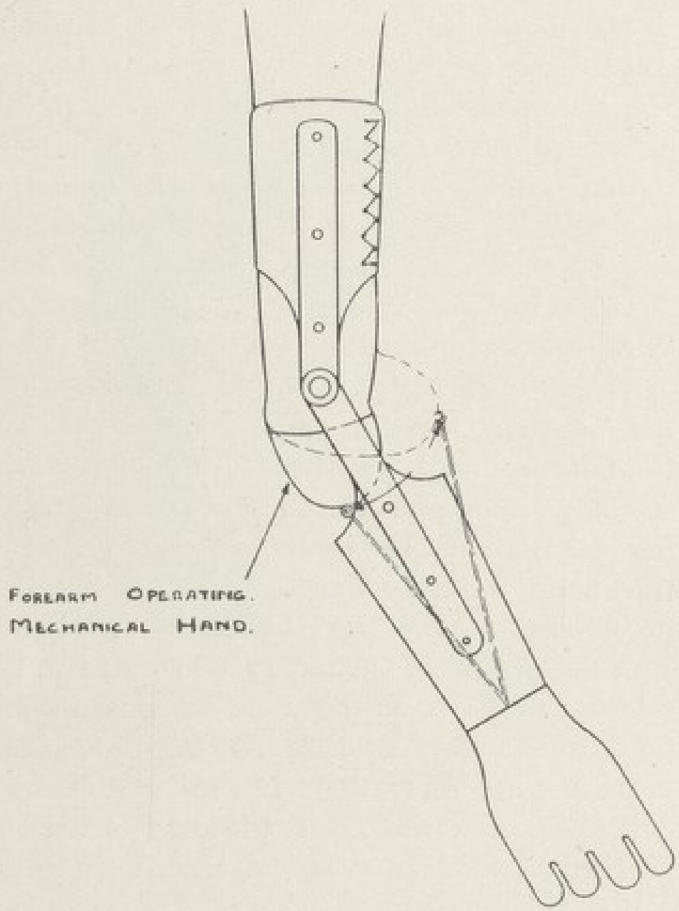


FIG. 130.
From a drawing by Mr. N. B. Jones of the Experimental Workshop of the Ministry of Pensions.

arm around and above the condyles of the humerus. These two lacing pieces form a corset laced behind and in front. It is found in practice advantageous to lace together only the two or three pairs of eyelets nearest the middle of the corset. The original Williams arm, as described in the *British Medical Journal* of January 15, 1916, p. 92, is essentially an arm for hard work, for which its inventor, Mr. Thomas Williams of Dunvant, near Swansea, devised and used it, having lost his own forearm 4 inches below the tip of the olecranon more than forty years ago. For this purpose the socket is made of strong stiff leather, with a very solid steel cap at the lower end, which can be used as a hammer or mallet.

The following description of the spring C hook and its attachment is given by Dr. W. L. Griffiths of Swansea (see fig. 131):

"Within the wrist of the forearm casing is a block of wood or other suitable material, over the outer part of which is firmly fitted and secured a dome-shaped metal cap or holder, H, having a central hole or socket, J, screw-threaded internally. A correspondingly threaded plug, K, provided with an outer flange, L, is adapted to screw into this socket. This plug is centrally bored, so that the shank, M, of the C-shaped hook can freely pass therethrough. The part of the bore nearest to the arm has an enlarged part, N, similar to a stuffing box, to receive a spring, O, which is coiled round the end of the shank when placed therein. This spring is compressed between abutments, formed by the shoulder, P, in the plug, and a nut or cap, Q, which is screwed on to the end of the shank, and is small enough to enter the space N. The plug, K, is then screwed into the socket, J, until the

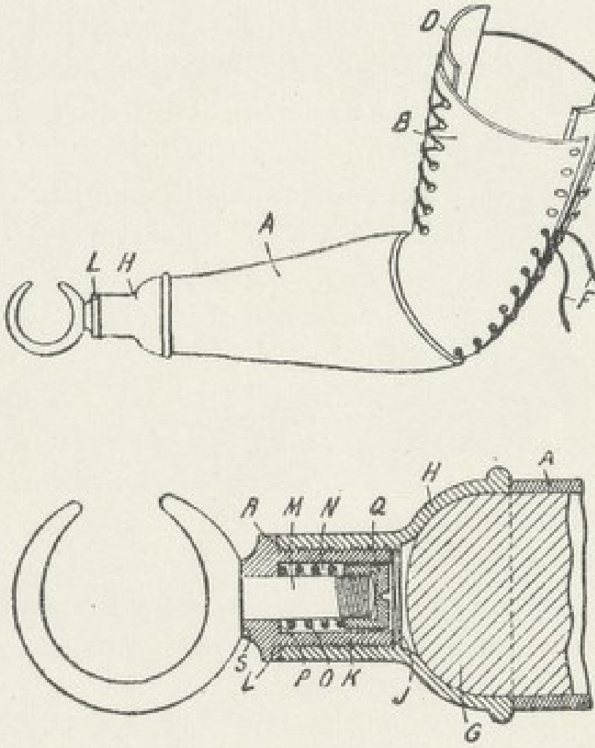


FIG. 131.

flange, L, meets its seating, R, and the appliance is ready for use. The hook, with its shank, M, is free to revolve axially in the plug, K, after the latter is screwed home, but is prevented from doing so too freely owing to the friction on the ends of the spring and between the base of the hook and its abutment, S. When a sudden pull comes upon the hook, the spring is further compressed and lessens the jar."

With this arm, despite his very short stump, Mr. Williams himself is able to do a great deal of hard work, could lift ½ hundredweight, and sling a 14-pound sledge-hammer. It is, however, not possible to flex the elbow fully with this arm, and therefore it is unsuited to some occupations. When made for ornamental dress purposes the socket is made of lighter leather, certalmid, or celluloid, and instead of the special Williams screw fitting a light snap catch is substituted, or when lightness is the chief desideratum, a light undetachable hand is affixed. It then becomes an excellent dress arm, masking mutilations for those who find shoulder and chest harness irksome; but in the case of very short stumps, the absence of an elbow lock detracts from its usefulness.

When the stump is so short that it can only be kept in the socket by fitting the latter very high up in front, so that full flexion of the joint is thereby prevented, an additional joint is sometimes fitted in the artificial forearm below the end of the stump. Flexion of this joint is effected by means of a shoulder control thong. By this movement it is possible to bring a fork up to the mouth. Such an arrangement is not often needed, except in the case of loss of both hands.

Workers' prostheses for long forearm stumps (F arms) which contain half or more of the length of the ulna do not need metallic elbow-joints. In order to retain the socket in place they are usually fitted with an upper arm corset, laced or strapped round the arm above the condyles, and connected by a pair of lateral leather straps with the socket.

When the Williams arm is chosen for such stumps, the special above elbow lacing pieces are used, as already described.

For hard work of a simple kind, a worker's forearm with a stiff leather bucket strengthened with steel plates and fitted with a hook and other appliances is most satisfactory. Some workmen who have to lift heavy weights with the arm find a shoulder harness necessary to take some of the strain off the supracondylar region of the upper arm.

The majority of F arms, however, are fitted with muscular extension of the thumb, and for the split hook or other grasping appliance. These are worked in the same way as for amputations above the elbow, but seeing that the patient has a natural elbow, only the one source of power is needed, and only one shoulder action need be employed.

Long Forearm Stumps.

The more elaborate workers' arms for these stumps, are the Adams, McKay, Pringle-Kirk, and Blatchford, all of which have their good points and their advocates among amputees.

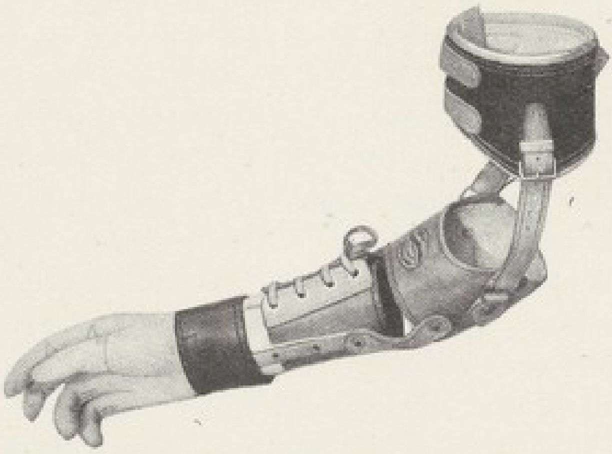


FIG. 132.—BLATCHFORD PROSTHESIS FOR LONG FOREARM STUMP.
The socket in two parts joined by straps only, allows movements of supination and pronation.

As a dress arm for clerks and some occupations the Carnes arm is successful. With these stumps the weight of the hand is not so much felt as in short forearm and above elbow stumps. The Cauet arm also gives good results, and has the advantage of a detachable hand and appliances (see figs. 115 and 116).

Wrist Stumps.

The drawback to all prostheses for disarticulations at the wrist is their necessarily disproportionate length. Provision below the end of the stump has to be made to receive the screw or snap catch pinion projecting from the wrist plate of the hand, involving a prolongation of at least ¾ inch. Owing to this necessary length of the socket, if the ordinary artificial hand is attached, the appearance when both hands hang by the side is asymmetrical. This disproportion is minimized in some light dress arms by making the hand a fixture, or, if the hand is detachable, the pinion is fixed to the end of the socket, and the female screw which receives it is in the hand instead of in the forearm. Too much should not be made of this difficulty, for as much as 1 inch extra of length will remain unnoticed if the coat sleeve is lengthened in proportion.

In all forearm stumps of amputations in the lower third of the ulna, and in cases of disarticulation at the wrist, it is desirable to fit a prosthesis that will allow of movements of supination and pronation, if it is found that these movements are still practicable.

If the ends of the bones are united by new bone or by scar tissue, the movement is impossible, and in such cases the question does not arise. When, as after amputations at or just above the wrist, the pronator quadratus survives, pronation is likely to be vigorous and useful. Unfortunately, after amputations above the pronator quadratus, it is often found that although passive rotation movements may be easy and of full or nearly full normal range, active movements are feeble and of small range. It is presumed that the supinator brevis and the biceps are active, but the pronator teres appears to be of poor efficiency. The loss of the triangular fibro-cartilage and of the rest of the lower radio-ulnar joint also handicaps attemps at rotation. Supposing that it is decided that voluntary rotation is powerful enough to be worth providing for, the end socket must be very short and connected by straps only with an upper forearm corset, as in the Blatchford G 1 arm. The end, or wrist, socket must fit closely enough not to allow the stump to twist round inside it, but at the same time it must not be so tight as to prevent the radius from moving round the ulna. This constitutes a difficulty which can only be surmounted by very careful fitting. In some working arms for long forearm and wrist stumps the stiff leather socket is moulded so closely to the lower ends of the bones that no rotation between them is possible. This is generally done in order to preserve the rotation movement by making the socket move with the bones without lost motion, but it defeats its object, although it is advantageous in another respect, in that it gives the stump a secure hold on the prosthesis.

Amputees who cannot pronate and supinate properly soon learn to substitute shoulder movements for the proper radio-ulnar movement, and thus to some extent get over the difficulty.

CHAPTER X

PROSTHESES FOR THE AMPUTATION OF BOTH HANDS, ETC., AND MUTILATIONS OF THE HAND

The plight of the man who has lost both hands is distressing, even if he labours under no other disabilities and if he has two long forearm stumps. With such stumps it is surprising how much a man can do for himself without prostheses, for by bringing them together he combines them into a prehensile organ or rudimentary hand, which has the great advantage over a prosthesis of possessing tactile sensation, which becomes more delicate with prolonged use. With the loss of each inch of bone in one or other stump the disability increases, until the lowest depth of deprivation is reached in the man who has lost both arms at the shoulder-joint, or a few inches below it. These unfortunates are happily few in number, but their case needs as much consideration as that of the more frequently occurring amputations. A remarkable facility in writing with a pen or pencil held in the teeth may be developed; many other light tasks may be performed by means of a stick, generally held in the mouth; but the best hope for them lies in the utilization of the feet, when these are uninjured. Persons who have been born without hands have been able to use their feet as prehensile organs with very great success and dexterity. The case of the truly limbless artist, Miss Sarah Biffin or Beffin, shows what may be done by those who are congenitally mutilated (see *The Dictionary of National Biography*). Whether mobility and prehensile power in the toes could be developed by giving up the constant use of shoes and stockings is yet to be demonstrated, but the remarkable usefulness of the feet to those who have been born without hands suggests the propriety of further study in this connection. In 1916 Mr. Sheehan invented a table fitted with levers to be worked by the feet for these cases (see *British Medical Journal*, May 5, 1917, p. 583), and Mr. George Thomson of Edinburgh has since devised a most ingenious machine on somewhat similar principles, which enables the truly armless man to do a variety of things (see *British Medical Journal*, January 3, 1920, p. 20).

This machine, however, is stationary, and the patient is nearly helpless when he leaves it. Attempts have been made to design a prosthesis of which the motive force is supplied by movements of the thigh and leg, but up to the present time (1921) they have not resulted in anything of much practical value.

Not only in these extreme cases, but in all those of loss of both hands or of more, the patient is unable to dress himself or to attend to the common needs of daily life or the calls of nature, and must depend upon the constant service of an attendant or relative. Even a cold in the head is a severe increase to the troubles of a man who has lost both arms above the elbow, so that it may be found best for him to keep his bed during an attack of catarrh.

With Thomson's table, after only a few hours' practice, an average man is able to feed himself and lift a cup and drink from it. With more practice he is able not only to feed himself with ready cut food, but he can cut it up for himself. He can write and do a variety of things which have been impossible for him since the occurrence of his mutilation. This table consists essentially of an ordinary table 3 feet 9 inches by 21 inches. The width may be much greater than this, but the measurement from back to front cannot be varied much if the ends of the levers are to reach to their proper positions.

The two levers are pivoted by their mid points at the back of the table, on which their angular (ball-and-socket) movement is very free. Each consists of a vertical part and two horizontal arms, one of which extends under the table, and the other to a corresponding position above it. On the end of each arm under the table is a plate on or under which one foot of the amputee rests, with a short upright rod passing between the first and second toes.

Any movement imparted by the foot to the end of the lever under the table is reproduced by the end of the lever over the table, which carries an ingenious snap grip to hold the various appliances.

These appliances are arranged in racks at the sides of the table, and by a most clever contrivance, an appliance can be easily replaced in the rack, released, and another one picked up.

Fig. 134.—Table in Use. The Demonstrator is feeding Himself with a Spoon.

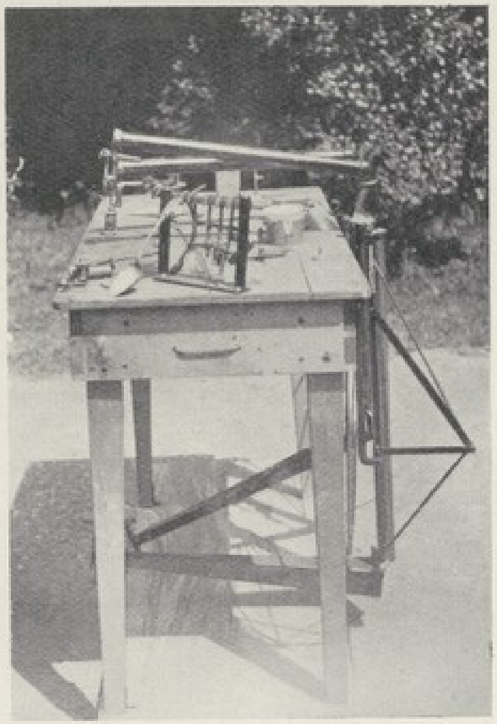


Fig. 134a.—Side View.

[To face p. 141.

By using both feet and both levers a two-handed action is obtained.

The table obviously will not enable a man to earn his living, but it renders the double arm amputee far less dependent on others than he was without it, and offers him very great opportunities of useful and mind-satisfying occupation to an extent which no other apparatus can do. Mr. George Thomson deserves

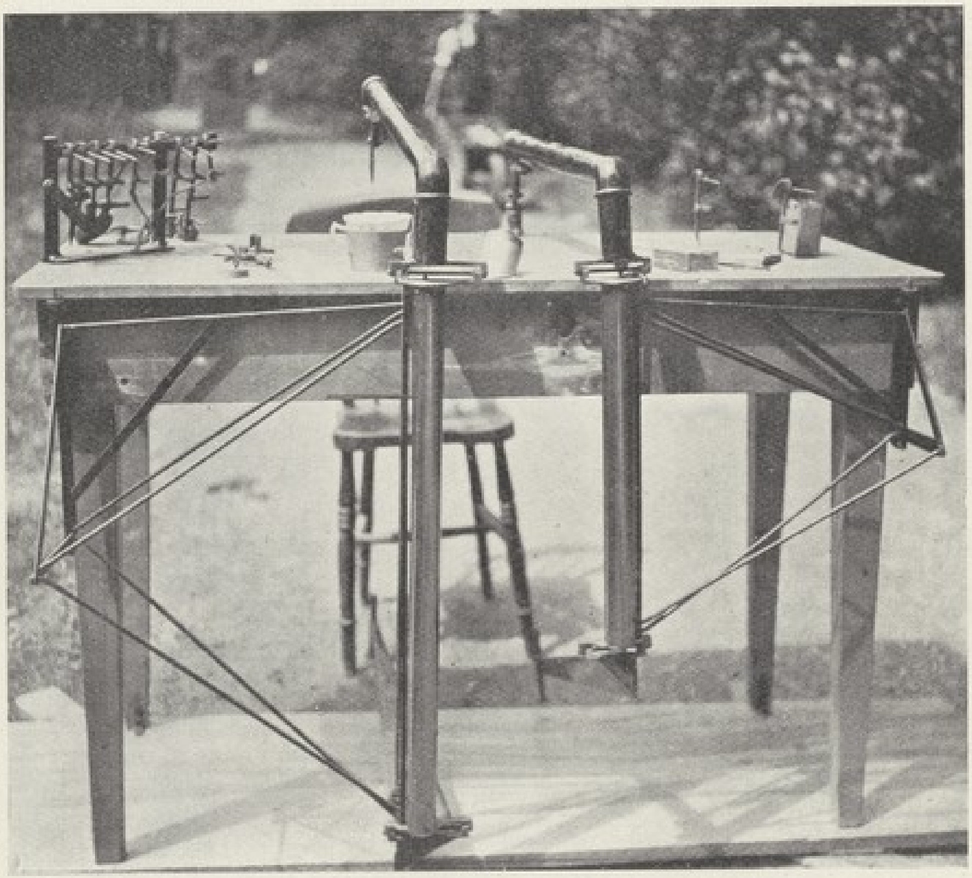


FIG. 133.—THOMSON'S TABLE, SEEN FROM THE BACK.

the very greatest credit for the ingenuity, perseverance, and public spirit which he has shown in inventing and perfecting his machine without any thought or hope of gain.

The mouth tongs devised by the present writer and improved in the Experimental Workshop of the Ministry of Pensions are shown in the figure. This simple appliance can be made of any convenient length, but is found most generally useful when about 9 inches long. It consists of a pair of forceps bearing a metal plate on each of the proximal ends, or handles, corresponding in its curvature with the line of the incisor, canine and bicuspid teeth of one of the jaws of the patient with a slight ridge of rounded form raised about $\frac{1}{10}$ inch on the posterior edge of each plate. These ridges rest at the back of the teeth, and prevent the tongs from slipping out of the mouth when the grasp is relaxed, in which condition the plates are kept against the teeth by the spring which opens the tongs.

In the simplest forms one pair of tongs is made to open vertically —*i.e.*, with one blade above the other—and another pair with the blades opening horizontally, so that the sides of an upright object, such as a chessman, may be grasped. When made of wood with metal mouth plates, such tongs weigh about $1\frac{3}{4}$ ounces.

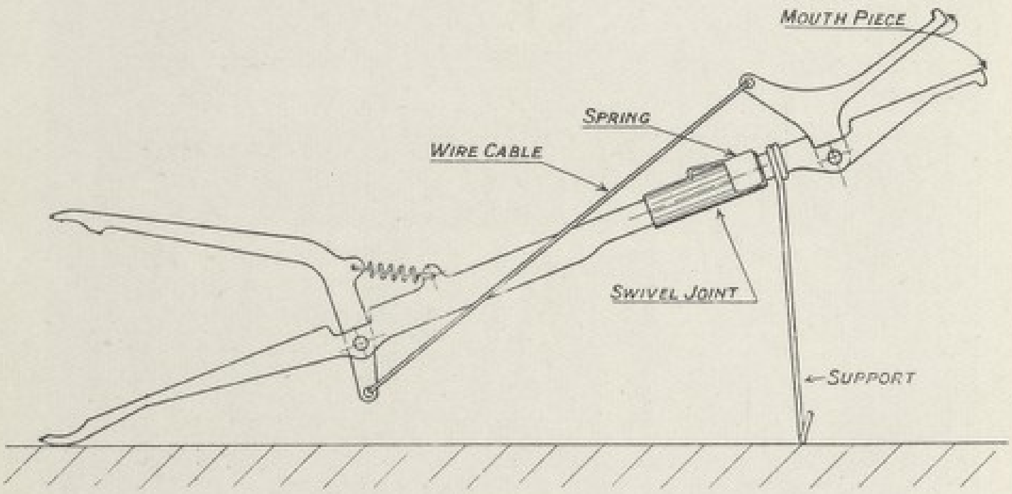
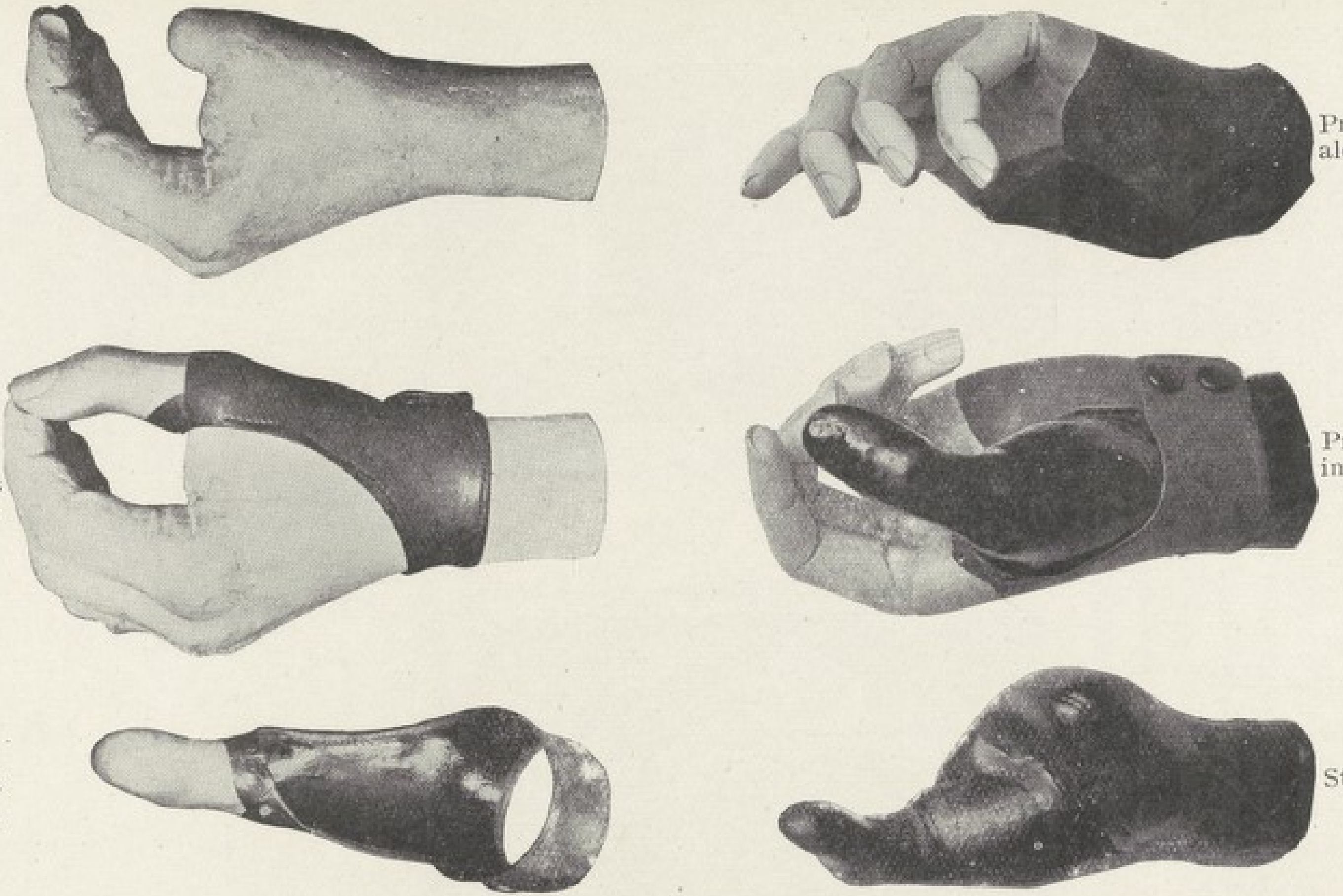


FIG. 135.

In the improved form made in duralumin the one pair serves for both purposes, as the jaws are made to be easily rotated on the long axis of the tongs as much as 90 degrees. This little help, being easily portable, can be used away from the Thomson's table (see fig. 135), which is unfortunately too large to be carried about.

When deciding what prostheses, if any, should be prescribed for double arm amputations, each case must be considered on its merits. In the first place, the question of earning a livelihood by manual labour may generally be excluded, although some determined individuals, having good long stumps, may succeed in certain occupations; but these will be found on examination to be more of a clerical than a manual nature.

A well-trained expert may be able to do all sorts of tasks with two arm prostheses, but he cannot perform them fast enough to make his work economically successful. When there is no



Stump. — Prosthesis in use. — Prosthesis alone.

Artificial thumb, to which natural fingers can be opposed.

Prosthesis alone. — Prosthesis in use. — Stump.

Four artificial fingers, to which natural thumb can be opposed.

FIG. 136.—PROSTHESES FOR MUTILATIONS OF THE HAND BY MESSRS. J. AND E. FERRIS, LONDON.

useful stump or veryshort ones above the elbow, it is not probable that any prosthesis will be useful; but if the patient wishes to try and mask his mutilation, a pair of light ornamental arms may be ordered. If there is only one good upper arm stump, an arm should, of course, be fitted to it, if possible with a useful mechanical hand. If there is one good forearm stump and one useful above elbow stump, a Carnes arm may be fitted to the forearm stump, with which the patient may be able to reach his own buttocks and attend to the toilet necessities of his person, and with the same arm and hand he can feed himself.

Fig. 137.

Fig. 138.

FIGS. 137 AND 138.—PROSTHESIS FOR METACARPAL AMPUTATION, BY ANDERSON AND WHITELAW.

It should be remembered that for double arm amputees the prostheses should be of the most widely serviceable kind, because it is impossible, or at best very difficult, for the patient without help to change his arms or his appliances. In the case of a patient who had one forearm amputated at the wrist and the other in its middle, these and other difficulties have been well surmounted by Mr. F. G. Ernst of London, who published an illustrated description of the case and of the various apparatus in 1893, to which the reader is referred for further details. But in higher amputations the difficulty of changing apparatus is likely to prove insurmountable.

Mr. Johnson Scott, who was born without hands, makes good use of the special hooks which are known by his name. With these it is possible to do many things.

For mutilations of the hand, the ornamental and the useful prostheses are usually best kept apart, and no attempt made to combine them except for patients not engaged in manual labour (see fig. 136). All such cases should be provided with ornamental fully articulated fingers, which are easiest fitted in a leather glove, or the more severe cases in a leather socket specially fitted to the stump and laced or strapped round the wrist.

Amputations of all the digits leaving the carpus or much of it intact are rare. Very few have been seen among the many thousands of cases treated by us at Roehampton. For such

FIG. 151.

FIG. 152.

(For figs. 139 to 150 and explanation of figures see p. 146.)

cases, when the wrist movement is good, a prosthesis has been devised in which flexion of the carpus pressed up the proximal end of a lever, which thus produced flexion of the fingers. The grasp with such an appliance, however, is not very strong, and the patient will generally prefer to use the naked stump, which may be made surprisingly useful. In cases of loss of both hands, however, such an appliance may have its uses.

When a useful thumb and one or more fingers remain, no working appliance is likely to be of any assistance, but when the thumb is totally lost, or all the fingers are gone, an artificial digit to which the thumb or finger can be opposed will prove useful. This is not made to resemble the lost part, but consists of a firm prop against which the living digit can be pressed so that objects can be grasped between the two. Such an opposition appliance is usually attached to the stump by means of a leather socket, and care has to be taken that this socket hinders the movements of the wrist as little as possible. The prop or appliance is sometimes made of wood, but is better made in two parts—namely, a metal socket attached to the wristlet, and a metal peg which fits accurately and tightly into it and carries a fibre plate on its distal end, against which the object grasped is pressed by the surviving digit. By this method the very valuable asset of sensation is conserved in the digit, the movements of which are hampered as little as possible. There is no standard form for these appliances, but some of those which have been supplied are represented in the annexed figures (for figs. 139 to 150 see plates opposite).

Explanation of Figures 139 to 152 of Mutilations of Hand and Fingers.

Fig. 139 shows a case of loss of all the digits, except the little finger.

Fig. 140. The working prosthesis for the same.

Fig. 141 shows the same in use. The hook can be removed and any conveniently shaped appliance substituted, to which the little finger can be opposed, thus forming a grasping organ.

Fig. 142. Ornamental fingers for the above. This prosthesis can be used for light work, as the little finger can be opposed to the wooden thumb.

Fig. 143 shows a case of loss of all digits, except the thumb.

Fig. 144. The same fitted with an opposition appliance, enabling a pen, etc., to be used.

Fig. 145. Fully articulated ornamental fingers to be worn in a glove. When the forefinger is flexed, the thumb can be opposed to it and used to hold small objects.

Fig. 146 shows a working prosthesis fitted to a case of loss of the three outer digits. The remaining ring and little fingers can be flexed upon the bar, so as to grasp objects firmly.

Fig. 147. The above prosthesis separately, seen from a distal position. The position of the palmar bar, to which the fingers are opposable, is clearly shown.

Fig. 148. Loss of fore and middle fingers.

Fig. 149. Fully articulated artificial fingers fitted to the above.

Fig. 150 shows the stump and prosthesis for a case of amputation of metacarpus.

Fig. 151 (p. 145). The same in use; the wrist is flexed and supinated by the action of the stump, and the spring thumb extended by shoulder action through the Bowden cable.

Fig. 152 (p. 145). The same in pronation and flexion.

For these illustrations, Figs. 139 to 152, the author is indebted to the makers, Messrs. Anderson and Whitelaw.

FIG. 139.

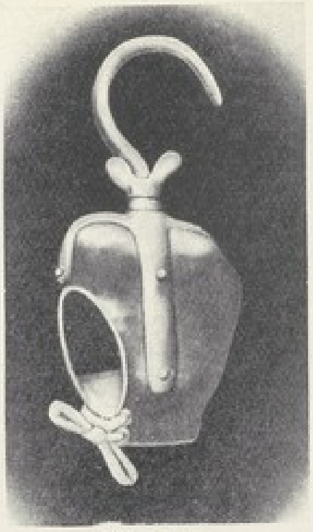


FIG. 140.

FIG. 142.

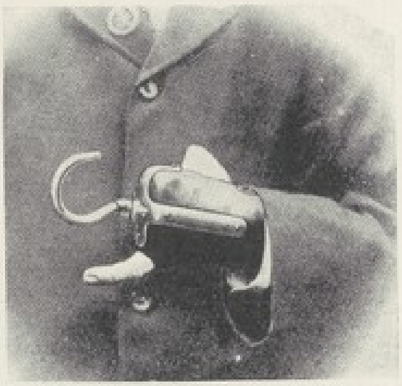


FIG. 141.

FIG. 143.

FIG. 144.

FIG. 145.

FIGS. 139 TO 145 (for explanation of figures, see p. 146).

[*To face p.* 146.

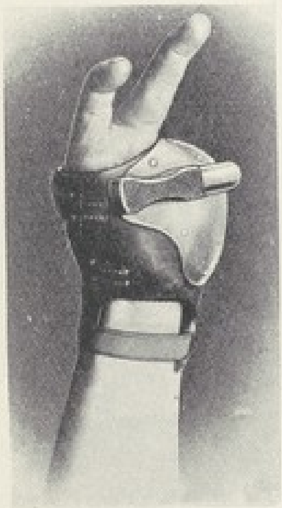


FIG. 146.

FIG. 147.

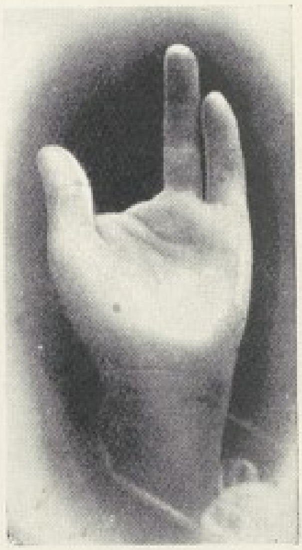


FIG. 148.

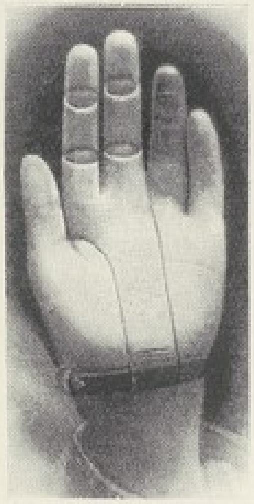


FIG. 149.

FIG. 150.

FIGS. 146 TO 150 (for explanation of figures, see p. 146).

[*To face p.* 146.

TH
co
wo
as
wi
wh
wo
ho
im

ap
Ro
me
wa
rus
bri
of

un
po
to

Li
em
Fo
to
file
of
ha
sh
is
ha

CHAPTER XI

APPLIANCES FOR USE WITH ARM PROSTHESES

THE most efficient artificial hands hitherto invented are of comparatively little use for manual labour. For certain light work the Carnes hand is used, and for heavier work hands such as the McKay and the Pringle-Kirk may prove useful; but it will be found that as a general rule one-armed or armless men who are employed in handicrafts use appliances in their daily work in preference to hands. Of these appliances the time-honoured hook, or one of its modifications, comes first in importance.

In the early years of the war a large number of ingenious appliances for various purposes were issued to pensioners leaving Roehampton, one of which was always a plain hook. When men returned for repairs or adjustments some months afterwards, it was not an unusual thing to find all the appliances rusty and obviously unused except the hook, which would be brightly polished by daily friction and would show other signs of wear.

The authorities then wisely restricted the issue of appliances until, after the establishment of arm-training schools, it became possible practically to ascertain which appliances would be likely to be of real use.

A visit to a workshop, such as that of the McKay Artificial Limb Company, where a large number of one-armed men are employed, shows that as a rule only simple appliances are used. For forearm amputations the hammer or file is fastened directly to the forearm socket. For upper arm amputees the hammer or file must be wielded by the sound hand, because the movements of an artificial elbow-joint and forearm are too weak for the hammer and not delicate enough for the file. Besides these a short piece of plain wood, which is pushed into the snap catch, is used to press against the work and to support it while the sound hand manipulates it.

Such a simple device is a primitive representative of a class of special appliances which have been devised by individual workmen for use in the workshop in order to perform special and often repeated tasks, but there are not many of these, and those that have been made are generally simple.

An example of a more elaborate appliance for a special task is shown in figs. 153 to 155, which represent an appliance which was devised and the first example actually made by Mr. N. B. Jones, a draughtsman in the Experimental Workshop of the Ministry of Pensions. Mr. Jones has an amputation of the left forearm, and constantly uses the appliance, with which he can do as much

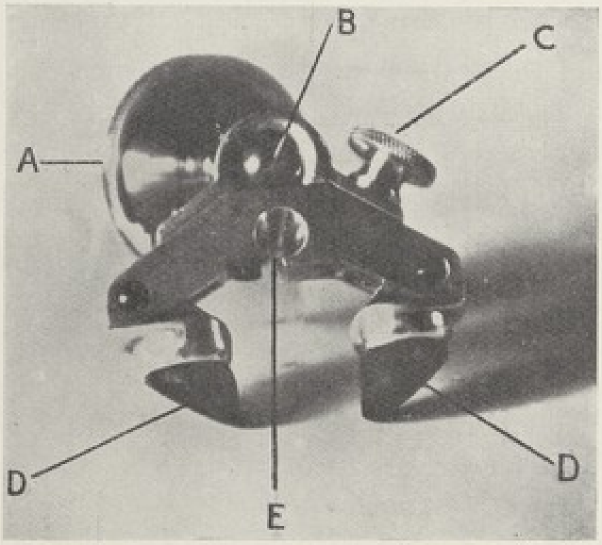


FIG. 153.—N. B. JONES'S DRAUGHTSMAN'S APPLIANCE.

A, Milled head which is screwed on to the forearm socket; B, ball-and-socket joint; C, screw which clamps the ball; D and D, rubber feet; E, pencil sharpener.

and as good work as he did before his mutilation. A number of the drawings illustrating this book have been made by him with the aid of this appliance. It is made of duralumin, and fitted to a light arm for forearm amputation. The two rubber feet are fixed at the end of legs so jointed to the body of the appliance that downward pressure of them against the desk tends to draw them closer together. One of these feet is placed on the T-square and the other on the set square. When the wearer rests the weight of his stump on the appliance, the set square is drawn firmly against the T-square. A small but useful addition is a pencil sharpener, into which the draughtsman inserts his pencil and rotates it with his sound hand. The labour-saving appliance for inking the drawing pen is shown in use in figs. 156 and 157. This was not specially designed for the use of amputees, but it is of even more value to them than to the two-handed man.

The split hook already referred to is the prototype of a number of appliances. It was introduced from America, where it is

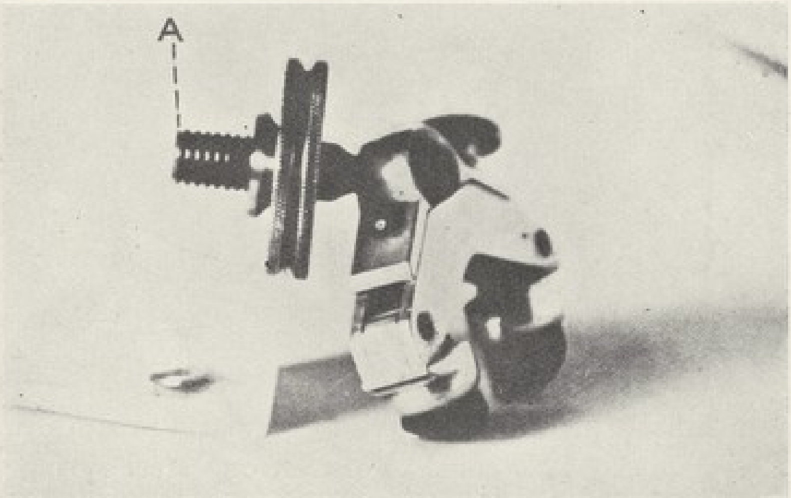


FIG. 154.—SIDE VIEW OF DRAUGHTSMAN'S APPLIANCE.

known as the Durrance hook, by Messrs. J. E. Hanger and Co. It consists of a C-shaped hook, which consists of two halves with a hinge at their bases, and kept together by a rubber band or

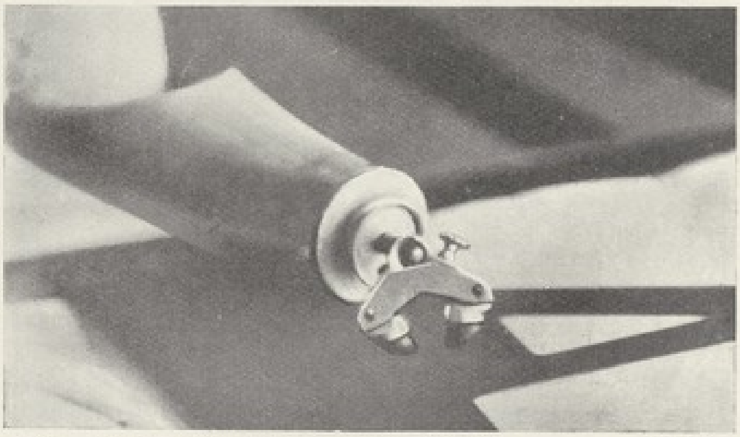


FIG. 155.—USE OF APPLIANCE WITH SET SQUARE AND T-SQUARE.

steel spring. One half carries an arm to which the same cord or Bowden wire is attached which is used to actuate a spring thumb, so that by exerting a pull from the shoulders the two parts of the hook are pulled asunder. When this pull is relaxed, the two halves are brought together again by the spring, and any object between them is thus grasped. It has the drawback, common to all spring-closed hands and appliances, that the power of grip is limited to the strength of spring which can be overcome by the shoulder pull (see fig. 163, No. 14, p. 155).

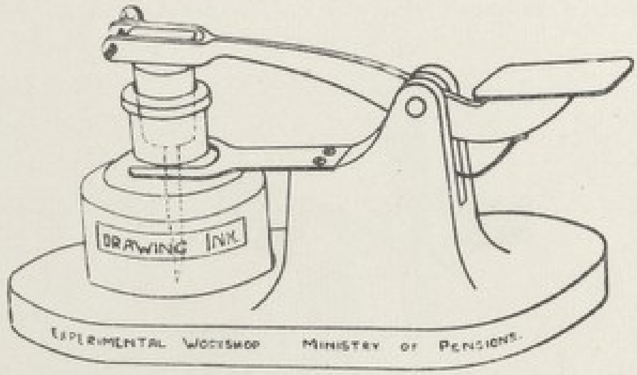


FIG. 156.—TIME-SAVING INKPOT FOR DRAUGHTSMEN.
With this appliance the drawing pen can be inked with one hand.

An appliance which is issued with every arm prosthesis is the nailbrush holder. This consists of a strong steel spring paper clip to which a standard screw or snap catch is attached. The

FIG. 157.—TIME-SAVING INKPOT IN USE.

clip grasps a wooden projection fixed to the back of an ordinary nailbrush, and is worked by the sound hand.

When the brush is removed, the clip can be used for holding such other objects as may be desired.

A good many ingenious devices have been produced to enable the arm amputee to cut up his food or feed himself, but few one-armed men care to avail themselves of them. The most generally useful help for this purpose is the Nelson knife, which is said to have been invented for the benefit of Lord Nelson after he lost his hand. It consists of a table knife with a re-

FIG. 158.—BLATCHFORD WORKER'S BELOW ELBOW ARM IN USE WITH BOND'S HOOK.

This shows Bond's hook in use by a fitter with a worker's below elbow arm.

curved end terminating in four prongs. The sharp convex edge is used to cut the food, and the knife is then turned half round and the mouthful picked up with the prongs. It is, of course, used with the sound hand.

All appliances are interchangeable either by means of the standard $\frac{3}{8}$-inch screw or snap catch. Appliances bearing the screw can be fitted into a snap catch socket by means of an adapter, and, similarly, appliances fitted with a snap catch can be used with a screw-threaded socket. A number of appliances made by various limb makers are shown in the following plates.

The McKay arm is peculiar, in that it is fitted with a double snap-catch—that is to say, that although there is only one retaining spring, there are two steel chambers for the reception of the shanks of appliances. Of these, the upper and smaller is of a well-known type, and receives the duralumin shank of the artificial hand. The lower, which is much larger, has a

FIG. 159.—CORY AND GRUNDY'S B 1 AND C 1 WORKER'S ARM WITH CERTALMID SOCKET, SHOWING APPLIANCE IN USE HOLDING A CHISEL.

number of longitudinal grooves, which receive corresponding ridges on a massive steel cylinder which forms part of the shank of each appliance intended for hard work. Thus a very strong attachment is formed, which will stand continual hard wear such as it is exposed to in the use of the hammer, etc. The annexed figures show some appliances in use.

FIG. 160.—A GROUP OF LIMB FITTERS AND MAKERS USING McKAY ARMS.

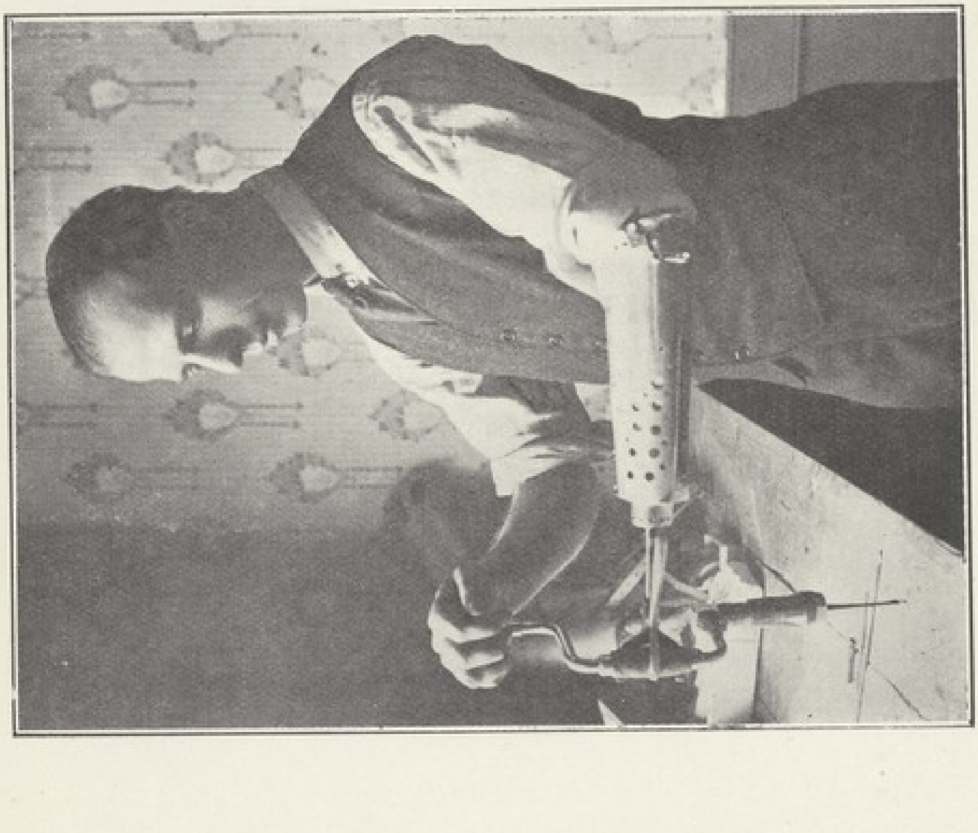


FIG. 161.—McKAY ARM USING DRILL.

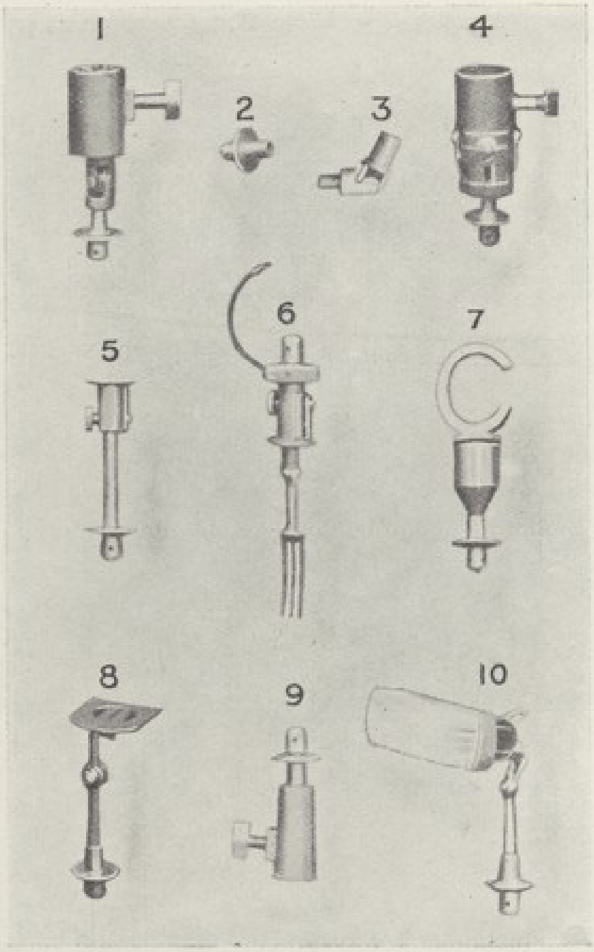


FIG. 162.—APPLIANCES FOR ARTIFICIAL ARMS MADE BY MESSRS. CHAS. A. BLATCHFORD AND SONS, LTD.

Nos. 1 and 4 represent tool holders for agricultural and other purposes. The end of the tool is inserted into the sleeve and secured with the milled-head screw.

No. 2 shows a snap-catch adaptor to enable appliances made with the standard screw thread to be used with a snap-catch socket.

No. 3 is a similar appliance with a universal joint.

No. 5 is an extension bar for use instead of a forearm.

No. 6 is a fork with rotation mechanism, which is actuated by a thong from the shoulder, and by which the fork can be supinated so as to convey food to the mouth conveniently.

No. 7 is an adaptor to enable a Williams' spring hook to be used with the snap-catch arm.

No. 8 is a paper or card holder.

No. 9 is a paintbrush holder shaped to take a taper handle.

No. 10 is a nailbrush holder. The brush can be detached and the spring clip used for various purposes.

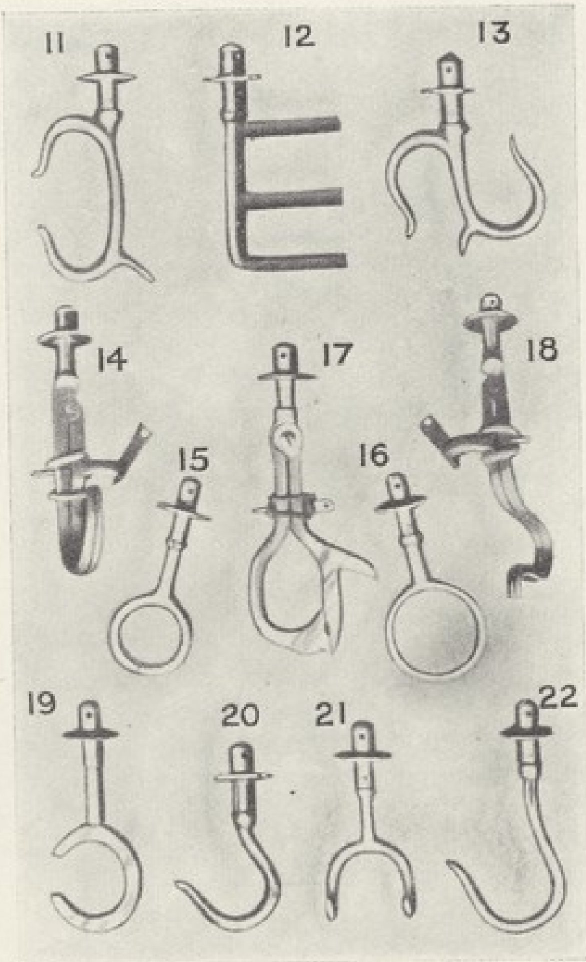


FIG. 163.—APPLIANCES FOR ARTIFICIAL ARMS MADE BY MESSRS. CHAS. A. BLATCHFORD AND SONS, LTD.

No. 11 is a long "C" hook for motor driving.

No. 12 is a rein holder.

No. 13 is a double "C" hook for agricultural work.

No. 14 is the standard split hook already described (see p. 150).

No. 15 is a small ring used to support the handle of a tool or lever. It generally acts as a fulcrum.

No. 16 is a large ring for similar purposes. It can be used on the handle of a barrow, etc.

No. 17 is Bond's split hook, which is useful for holding nails and other small objects.

No. 18 is a split hook for double amputations.

No. 19 is an ordinary "C" hook; one of the most generally useful appliances made.

No. 20 is a small and No. 22 is a large plain hook.

No. 21 is a double hook for use by men handling sacks and bales of goods.

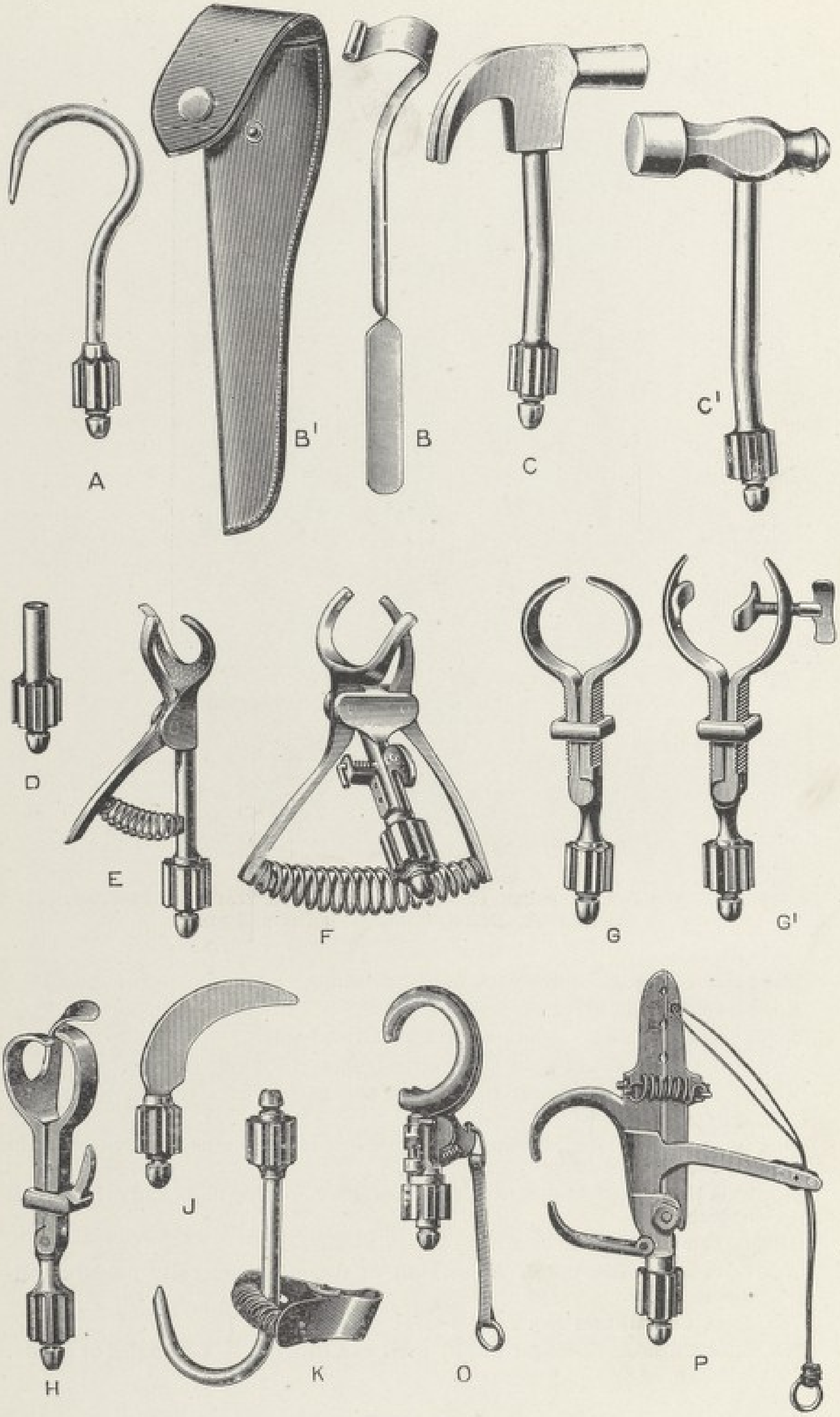


FIG. 164.

FIG. 164.—APPLIANCES MADE BY MCKAY ARTIFICIAL LIMB CO., LTD.

A, Plain hook, which can be instantly set at any required position in arm socket, adding considerably to its value as a plain hook.

B, Special table knife with spring steel curved end, which firmly grips on to fifth metacarpal bone, the blade being held between thumb and index finger.

B^1, Leather pocket sheath for table knife.

C and C^1, Claw and riveting hammers. These hammers are probably the most useful appliances, as they can be instantly set to any desired angle, and the user, even in above elbow cases, can deliver a hard true blow, leaving his natural fingers free to do all fine manipulating.

D, File holder having a hollow centre with hardened thread. Will firmly grip the tapered end of files, chisels, etc. Is invaluable to the wood and metal worker.

E, Brace and chisel grip. This appliance, the jaws of which will firmly grip the handle of the brace, is fitted with a rotating adaptor, and thus enables the user to drill holes at any angle without changing position in the arm socket. It is also used for holding wood chisels and similar articles.

F, Shovel grip. This appliance is specially adapted for use with very long, straight-handled tools, such as shovel, hay fork, hoe, rake, etc., having a shoe attachment which enables it either to lock in any position or flex freely. It is also used in paper-hanging and sign-writing.

G and G^1, Spade and wheelbarrow grip, with rotating head, is specially designed for use with D shaped tools, such as spade, etc., also for wheeling a barrow. It is slightly altered in G^1 for gripping along handle of spade, or gripping end of oar, allowing of full length of stroke.

H, Saw grip, specially designed for gripping handle of saw, is especially useful in mitre-box work.

J, Hooked knife, used chiefly for cutting and shaping leather work, as in boot repairing.

K, Painter's hook, fitted with a spring clip for holding paint or varnish brushes. Two check screws allow the clip to be fixed to any position in which the brush is to be used.

O, Mechanical spring split hook fitted with rotating head to allow of free movement when required. There is also a spring bolt which will hold the hook in any fixed position. This is a very useful appliance for general work, and is adaptable to a great variety of uses, including carrying, wood planing, chiselling and filing, tying string and boot-laces, holding papers, dishes, needle, knife, spoon, and many similar uses.

P, Universal pliers, fitted with rotating adaptor, specially designed for gripping and holding small articles, such as screws, nuts, punches, and various similar articles, as in metal working. A hook with adjustable head or keeper has been found a useful addition.

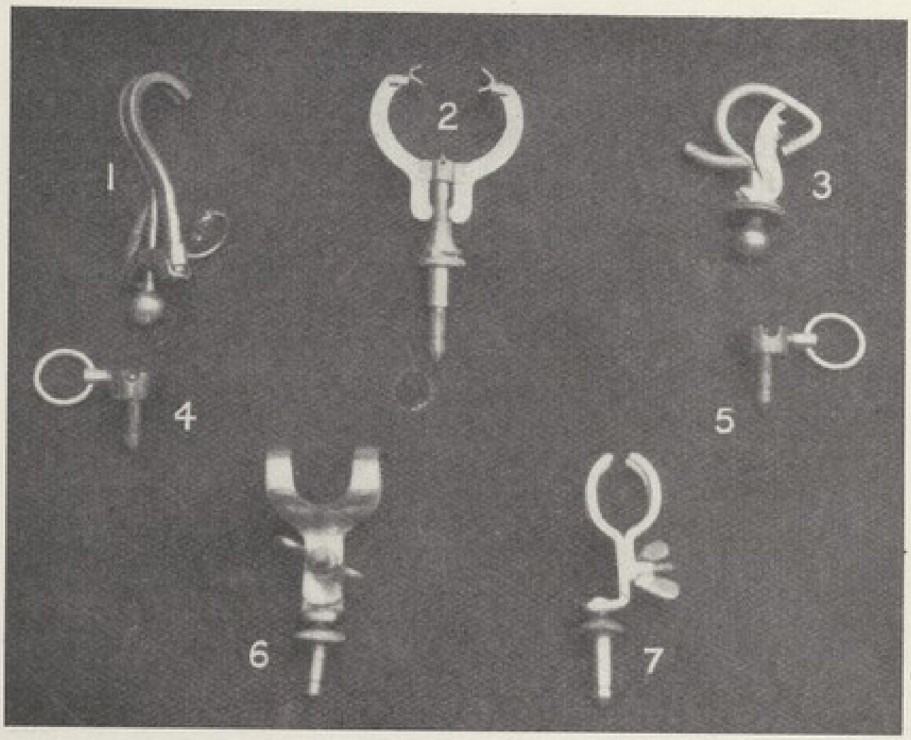


FIG. 165.—APPLIANCES FOR USE WITH ARTIFICIAL ARMS SUPPLIED BY MESSRS. CORY AND GRUNDY, LTD.

No. 1. Split hook mechanically or manually controlled; the nearest leg on photograph, if depressed toward the ball, may be turned round, thus forming a loop. The ball of No. 1 snaps into ball socket No. 4, which is fitted with a six-spline adaptor to suit Cory and Grundy, automatic snap-catch either in wrist piece or the T piece of elbow-joint.

No. 2. Cory and Grundy's new Universal tool holder, recently placed on M.O.P. Consolidated List, the outstanding feature being the quick application of same. The shank or stem has a square worm turned on it, and by pressing a stud which projects from the cone the latter may be pressed forward, thus bringing the small grips together instantly. By removing the pressure from stud the cone is positively locked instantly, enabling the user to hold a chisel, brace, or the like. By turning the grips 90° the appliance holds a hammer quite satisfactorily. While the grips are in this position a nail, screw, pencil, or the like can be gripped quite well. By turning the grips outward the appliance may now be used for working a plane or the like. This appliance also has a six-spline adaptor, as in No. 1.

No. 3. This tool holder is formed of a ⅜-inch round mild steel central body or hook, and one flat steel toothed member on either side. The latter are forced forward toward the V portion of the hook, and form a grip of good range; by screwing the round knurled disc forward the two flat members are easily detached, thus allowing the appliance to be used as an ordinary hook for its known uses.

No. 4. As described in No. 1 (for left arm).

No. 5. Same as No. 4 (for right arm).

No. 6. Spade or agricultural appliance fitted with a new patent ball joint designed especially with full rotation, but with limited lateral movement, to obtain the best results for the purpose it is designed for, and is only one-third the weight of an ordinary ball joint.

No. 7. Side view of No. 6.

CHAPTER XII

PERMANENT PEG LEGS

In the days when for below knee amputations the site of election at a hand's-breadth below the knee-joint was in vogue, kneeling peg legs resembling that described and figured by Paré were much used, and they are still made. The outer upright or fork is, however, carried up as high as the pelvis, and is secured by a strong strap and buckle which passes round the ilia and above the great trochanters (see fig. 166). Such limbs were also used for amputations through the knee-joint or above it in those cases in which the full weight could be borne on the end of the stump.

As a rule, however, permanent peg legs or pylons are made with wooden or leather sockets, fitted in precisely the same manner as those of complete artificial limbs. The old-fashioned "Chelsea Pensioner" leg for the sake of cheapness, strength, and lightness, has no knee-joint, the wooden peg being pushed "hand tight" into a socket at the end of the knee piece. In case a new peg is needed, it is simply pushed into the old socket (see fig. 167).

Such a prosthesis, however, is very awkward when its wearer wishes to sit down, as the socket cannot follow the flexion of the stump unless the peg leg protrudes horizontally in front of the patient; or if the end of the peg is allowed, as is usual, to rest upon the ground, the back part of the top edge of the socket will be pressing uncomfortably into the buttock. This position has the additional drawback that the peg is very much in the way of other persons, especially in public conveyances. For these reasons, permanent peg legs are now generally made with a mortice in the lower end of the knee piece. The upper end of the peg is expanded into a tenon which fits into this mortice, where it is secured by a transverse steel bolt, with a leather bush. A spring catch at the back of the knee automatically locks it as soon as the fully extended position is attained, and the wearer walks with it thus locked. When he wishes to sit down, the lock is released by pressure with the hand on a flute-key lever at the back of the thigh. In order to avoid risk of accidental release of the lock, the lever is sunk in a recess in the wood so as to present a flush surface when the knee is locked.

For amputations below the knee with sufficient length of stump a permanent peg leg is occasionally used, such as is repre-

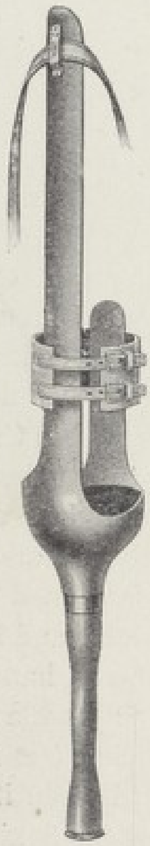


FIG. 166.—KNEELING PEG LEG FOR AMPUTATION BELOW KNEE, THE WEIGHT BEING TAKEN ON A CUSHION.

This leg is also made with padded cradle for long stumps or for resting foot, ankle, etc. A special pin to deaden sound when walking. The leg is attached with straps.

FIG. 167.—BUCKET AND PEG LEG.

These are for cases of amputation above knee, and can be made with or without knee-joint and catch. The former is very convenient when in a sitting position, and is quite rigid when walking. The bucket is made in willow wood or solid leather. The pin can be fitted with rubber to deaden sound. Attached by means of braces or waist strap.

sented in fig. 168. The writer is indebted to the maker, Mr. Horace V. Duncan, for this and the two foregoing illustrations of peg legs.

Articulated permanent peg legs have many advantages for rough work. They are light, and the centre of gravity is high—

generally at or above the knee-bolt—so that the leverage strain on the stump is much less than in a complete prosthesis, and the fatigue from wearing one is much less than that from the last named. If they are to be used on soft ground, however, into which the simple peg would sink, the lower end must be expanded into a larger surface, or a "rocker" foot such as that of the Beaufort leg may be added (see fig. 14, p. 13).

Æsthetic considerations have, however, in this country prevented many men from accepting peg legs even as a duplicate issue. The desire to conceal their mutilations as far as possible is extremely strong among the pensioners of the British Services.

Whatever form of peg is used, the end must be shod with sole leather, to which is often added a rubber pad, such as are used for the heels of boots. In the case of the simple unexpanded end of the peg, the leather shoe is removable, and a new one is easily slipped on in place of a worn one.

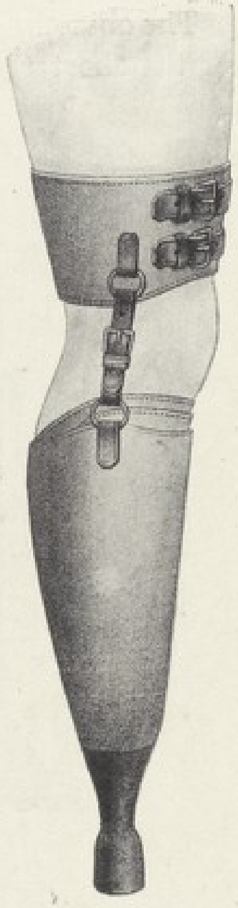


FIG. 168.—SOCKET PEG LEG, FOR AMPUTATION BELOW KNEE, WITH LONG STUMP.

It is made of willow wood, and fitted with or without steel side joints according to stump, and is fastened by a soft leather bandage above the knee. It usually has a soft knee-cap for stump. The pin is of hard wood, the end of which is either leather or rubber covered. A shoe to lace on can also be supplied.

Besides the above-described wooden peg legs, which have stood well the test of time, in recent years various metal pylons have been devised, such as that of Spitzy (see fig. 169).

Another ingenious metal pylon is that devised for himself by Mr. Winthrop Young. This has two peculiar features: (1) For a short thigh stump there is a working knee-joint used in walking as in a complete artificial limb, but this knee-joint is placed close to the end of the stump, and consequently at a much higher level than the normal knee. (2) The leg part, which is made of steel bicycle tube, can be shortened or lengthened at will by means of a sleeve and catch (see fig. 170).

The following advantages are claimed for this pylon:

1. Owing to the high position of the knee-joint, and consequent shortness of the thigh lever, the muscles of the stump have less work to do, and fatigue is consequently diminished.

2. By lengthening the leg part in going downhill and shortening it in going uphill, walking is much facilitated.

The obvious objection to this pylon is the unsightly appearance of the short thigh and long leg. The inventor, who is an ex-

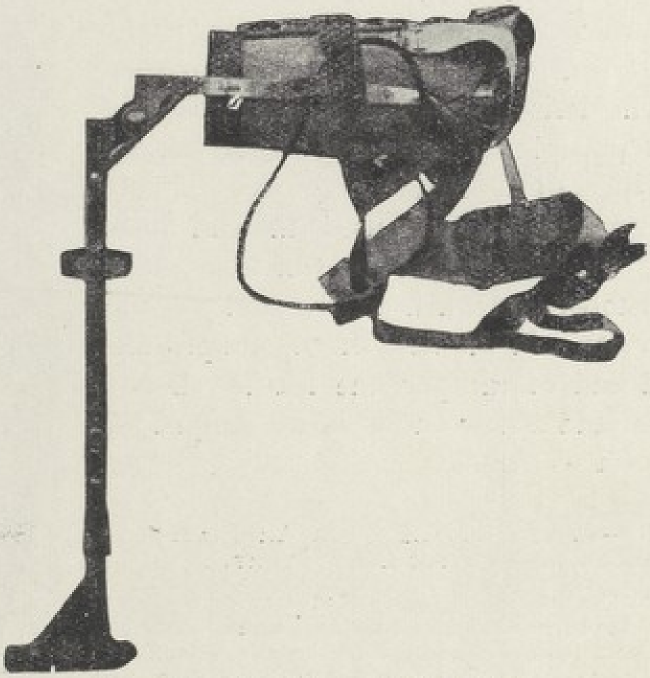
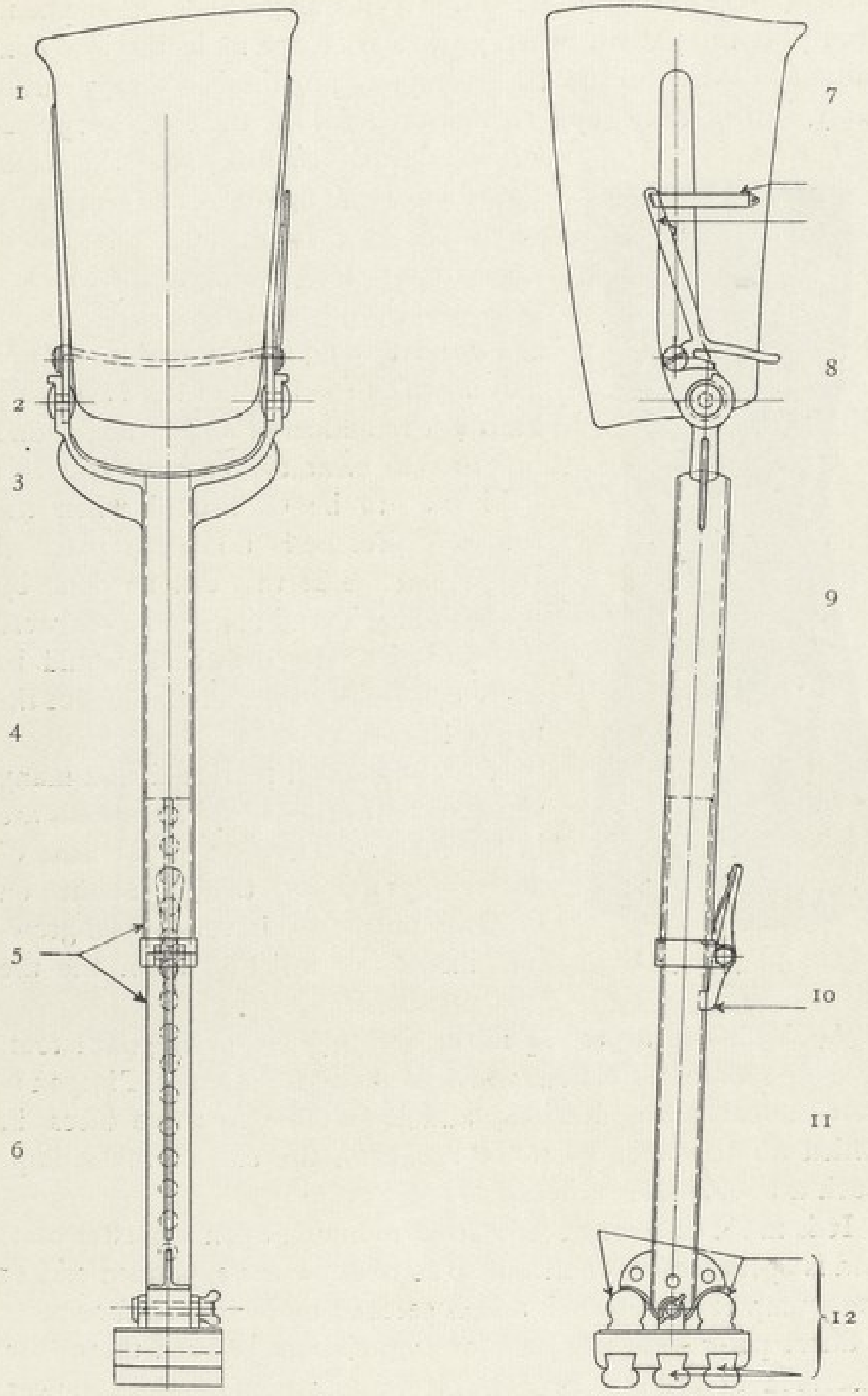


FIG. 169.—SPITZY'S METAL PYLON.

perienced mountaineer, has himself found this leg of great practical use, and proposes to use it to ascend the Matterhorn.

The peg leg is particularly useful in civil practice in the after-treatment of children and young persons whose limbs have been amputated on account of accident or disease. After the temporary peg, which is discarded as soon as the skin-wound is healed, a permanent peg leg should be ordered and worn, and the length adjusted to the growth of the patient by changing the peg for a longer one as often as necessary, the same socket being used as long as it can be made to fit comfortably.

Crutches should hardly ever be used by young amputees. The prescription of a peg leg not only facilitates locomotion, but by restoring function as far as possible to the muscles, bones, and



Fore and aft view. Side view.

FIG. 170.—WINTHROP YOUNG'S ADJUSTABLE PYLON.

1, Socket; 2, knee lock and joint; 3, steel stirrup; 4, outer steel tube; 5, telescope lock; 6, inner steel tube; 7, socket; 8, knee lock; 9, outer steel tube; 10, telescope lock; 11, inner steel tube; 12, rubber buffers on rocking plate.

other tissues of the mutilated side it encourages their development and puts the patient, when growth is complete, in the best condition to make full use of a complete prosthesis. The wealthy may, if they wish, supply a new artificial leg and foot every year or so during growth, but the child appreciates the lightness and simplicity of the peg leg. It is true that for above knee amputations, owing to the absence of movement at the knee, peg legs have the disadvantage of fostering a mode of gait in which the thigh of the advancing limb is circumducted and swung round in order to clear the ground, and this habit has to be eradicated when the complete prosthesis takes the place of the peg leg. But this can be done by perseverance in training, and even were it to persist, the drawback would be slight compared to the advantages of the use of the peg.

Fig. 171.

It is to be much regretted that many surgeons and other hospital officials are in the habit of advising, or at least of allowing, patients to go about on crutches until they have stopped growing, instead of insisting upon the use of a prosthesis.

Analogous to a peg leg is the stump boot, or elephant foot, as it is sometimes called, which is made for Syme's, Pirogoff's, and Chopart's amputations, and is suitable to those cases, in which all the weight can be borne on the end of the stump. Such a boot is shown in fig. 171.

It is made of strong sole leather moulded upon a plaster cast, and is opened down the front so as to allow the expanded end of the stump to be inserted, and is secured by lacing, as shown.

Short permanent peg legs for amputations of both thighs are described in Chapter XVIII., on Amputations of Both Lower Extremities.

CHAPTER XIII

NORMAL HUMAN GAIT AND GAIT WITH AN ARTIFICIAL LEG

NORMAL gait has been studied by the Brothers Weber, who published diagrams illustrating it in the classical work on the " Mechanics of Human Gait " in 1836.[1]

These authors, however, had not the advantages conferred by instantaneous photography and the cinematic camera. Since their time the subject has been studied by O. Fischer in Germany, and Amar, Marey, and Ducroquet in France, and others. Dr. Ducroquet has studied not only normal but pathological gaits cinematically, and has published instructive diagrams in his book, " La Prothèse Fonctionnelle des Blessés de Guerre."

Fischer obtained his records by means of Giessler's incandescent tubes, one of which was strapped to the outer side of each thigh and each leg of the subject of observation. These tubes were momentarily lighted up at given intervals of time, while the subject walked along a marked track in a room as nearly dark as was consistent with his seeing his way.

Professor du Bois Reymond[2] used this method for the study of the gait with an artificial leg, presumably for an amputation above the knee. Two cameras with uncovered lenses were used, one on each side of the patient, so that each camera recorded the movements of one leg only. A spark was passed through the tubes twenty times a second, so that twenty images per second were made upon the plate. The annexed figures show some of the records thus obtained. (In what follows the word " shin " is used for the leg below the knee.) The following facts appear to be established by the photographs taken by this method:

1. In swinging forward, the artificial shin remains much less behind than the normal.

In slow normal gait the knee tends to bend as much as

[1] "Mechanik der Menschlichen Gehwerkzeuge," Göttingen, 1836.

[2] This abstract is quoted from the *Medical Supplement* to the *Daily Review of the Foreign Press*, vol. i., No. 8, August 1, 1918, pp. 242-244.

140° to 130°, but in an artificial limb 20° to 30° less. Artificial limbs of different makes vary much in this respect.

2. While the artificial limb rests on the ground and supports the body it remains in full extension (at knee). In normal gait the knee during support is slightly bent. Both these facts may be noted as constant characteristics of walking movements with an artificial leg. Both are easily attributable to simple mechanical causes.

In normal gait, if the toes are raised from the ground, the shin instantly swings free, while the thigh is brought forward. Through movement of the thigh the upper end of the shin (*i.e.*, the knee) is also drawn forward; the lower end remains at first behind, so that the bending of the knee is accentuated. As the thigh comes farther forward the shin follows it with increased velocity, so that the bending of the knee again diminishes. Soon after setting down of the foot the forward movement of the thigh ceases, and as the shin again swings free, the leg comes at once into extension.

In artificial limbs, obviously, the thigh cannot be drawn up at the beginning of the swing; thus bending of the knee is brought about exclusively through the lagging behind of the shin, and is consequently weaker and slower. Add to this that the mean centre of gravity of shin and foot in the natural limb is about the middle of the shin; in an artificial limb with boot it lies lower.

The cause of the differences between movement of the artificial limb and normal gait movements—namely, that the knee in supporting position remains extended—lies simply in this, that muscular action, which could make support possible in slight flexion, is wanting in the artificial limb.

3. A third difference between the movements of the two consists in this—that the hip of the artificial limb side, while the limb swings, is raised considerably higher than in the natural limb.

Since the artificial limb at the beginning of its swing cannot be moved by muscular action either in knee or ankle joints, and hence swings in less flexion, it has the tendency to scrape the floor with the toes. This can be avoided by increased lifting of the hip. The hip must, however, also be raised if the body, as happens in normal gait, is inclined to the other side.

Besides this, to the artificial limb bearer proper support from the ground is wanting, such as exists at least in many kinds of natural gait. It is to be supposed that the artificial limb bearer makes up for this want through a shuffling movement of the buttock. In order to settle this point the author took records of the fore and aft inclination of the buttock in artificial legs, whence it appears that also in this the artificial limb walk differs from the natural, and that much greater pelvic movements (fore and aft) occur than in normal.

Various circumstances combine in the increased raising of the hip. In some cases, especially of beginners, the hip and whole body are pulled forcibly up and to the supporting side, in order to slide (shuffle) the artificial limb with the necessary swing forwards. This very clumsy movement diminishes after more practice, but in most cases the increased lift of the hip remains permanent. The wave line which the hip describes has in differently trained walkers different forms. In some the summit is reached early, and the greater part of the wave is taken up by the descent; in others the summit is near the end, so that the wave ends with a steep fall. Probably the same object is here attained in different ways. The rise and fall of the wave may be in other cases quite symmetrical.

In connection with the excessive lift of the hip, especially in those cases where the summit of the wave lies at the end of the swing, a fourth divergence of the artificial gait from normal is found, which consists in this—that the leg, before the foot is set down, is swung too far forward and then drawn back. In normal gait exclusively forward movements are made. Relative backward movements occur, but not absolute—that is to say, the limb moves backwards as regards its relation to the trunk, but does not move backwards as regards its position in space. Such a movement is a waste of effort. It often occurs with unpractised artificial limb wearers, when either the artificial or the sound limb makes a backward movement.

In the records the crossed lines show this movement. Such crossing occurs if the thigh is drawn back before the end of the swing of the leg more forcibly than in normal gait, in order to shift the shin forward. Further, crossings appear in the plates if the leg is thrown too far forward before the foot is set down, and must be drawn back again in order to reach the ground.

Comparison of Records of the Sound Side with the Normal Gait.

The one remarkable deviation from normal gait on all the records (*Aufnahmen*) of the sound side consists in increased lifting up of the hip during the swing. Of this there is just the same to be said as of the artificial limb side.

Besides this, one sees also on the sound side in some cases the " crossed picture " that is caused by a backward movement of the leg in space.

In particular, at the end of the swing the thigh is moved much too far forwards, and then back again. Special attention is called to the case of the practised artificial limb walker who used three artificial limbs of various makes one after the other, and each time made the same fault with the sound limb. This observation is important, because it shows that the faults in artificial limb gait may depend not only on mechanical, but also on physiological causes.

Obviously, the case is to be thus explained—that a man in the trouble of mastering the unaccustomed artificial limb makes too energetic movements of his stump. Through the bilateral connection in which the nerve centres for the movements of the leg stand to one another, this effort involuntarily causes too great activity of the sound limb as a result. Hence, it comes about that in learning to walk with an artificial limb it is not only necessary to learn to carry out the correct movements of the stump, but the sound limb also must be taught anew to refrain from excessive movements brought about by co-ordination with the stump.

The deviations, described above, from natural gait of the artificial limb may not be very obvious to superficial observation. It must, however, be pointed out that they have a very important influence on the amount of effort expended in walking. According to Fischer, the hip in normal fast walking is raised and lowered about 4 cm. at each step. Equally great is the rise and fall of the centre of gravity. According to Kattzenstein and Zuntz, the total work of a 55·5 kg. man in walking amounts to 315·4 mkg. a minute. The lifting of the centre of gravity alone must in eighty steps a minute therefore be reckoned as $80 \times 0{\cdot}04 \times 55{\cdot}5 = 177{\cdot}6$ mkg., about half of the total work. If the raising of the hips and of the centre of gravity is double the normal height, as not seldom happens in artificial limb gait, then the work caused by the lifting is increased to 355·2 mkg. a minute; thus, the lifting alone entails more expenditure of work than the whole walking movements do normally. If all other conditions were to remain the same, then the work of walking with an artificial limb would, through exaggerated lifting of the hip, be increasd to 164 per cent. of the normal.

One can from these data estimate how much the effect of walking may be increased by apparently slight alterations of the movements made, and thus the necessity of investigating the artificial limb in such a manner as to distinguish slight differences in movement becomes apparent.

Further details of the method employed will be found in the abstract of du Bois Reymond's articles which appeared in the *Medical Supplement* (as above).

Professor du Bois Reymond does not state what kind of artificial limb was used, but it is not likely that it was one having shoulder control on the American principle. Probably an elastic knee extension of some kind was fitted. The differences between the records of gait with a normal and artificial limb were much greater than those found in the records produced at the Experimental Workshop. The discrepancy may be due to the kind of prosthesis used, to the difference of amputation stumps or of the skill of the wearers.

At the Experimental Workshop of the Munitions Inventions Department at Thames Ditton an investigation into the normal gait and that with an artificial limb was carried out in 1917. Exposures were made at the rate of 160 a second, and the film thus obtained, when projected upon the screen at the rate of about sixteen to the second, produces the effect of an extremely slow movement—much slower than any that can actually be made—and enables observers to determine the nature and exact sequence of the movements which constitute a stride.

For the following notes I am indebted to Mr. Henry Longmate, A.M.I.Mech.E., Director of the Artificial Limb Section of the Munitions Inventions Department of the (then) Ministry of Munitions.[1]

[1] Since transferred to Roehampton under the control of the Ministry of Pensions.

Analysis of Walking Movements.

The accompanying Cinematograph Chart No. 1 shows a series of successive positions of a human leg during ordinary walking, and was prepared from a cinematograph film of an uninjured man who walked in his usual manner on a wooden horizontal platform in front of a screen divided by white tapes into 10 cm. squares.

EXPERIMENTAL WORKSHOP, ARTIFICIAL LIMB SECTION, MINISTRY OF PENSIONS.

CINEMATOGRAPH CHART No. 1.

Natural Walking on the Level (with Boots), One Complete Stride.

The accompanying table of the angles recorded on Cinematograph Chart No. 1 shows up the following salient points (see fig. 172):

1. *Flexion of the Knee.*—The maximum flexion with *toe in contact with ground* is 35 degrees (from the straight line of the leg—*i.e.*, 180 degrees). Immediately the toe leaves the ground (at No. 9) the flexion is nearly doubled, increasing to 68 degrees in the three following pictures.

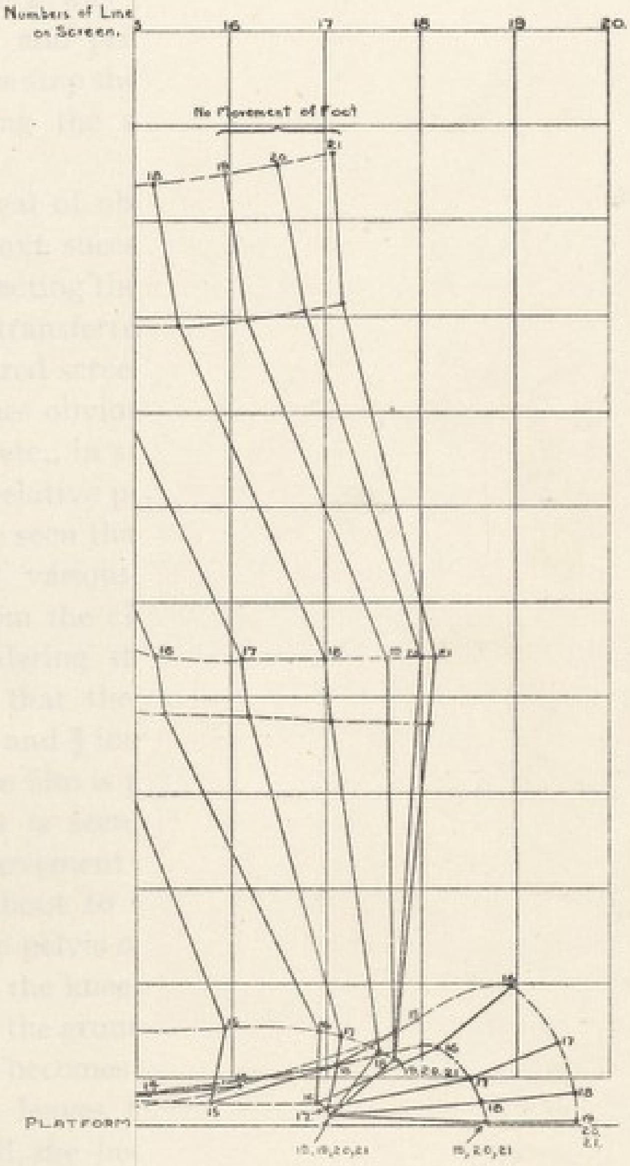
It will be seen that at Nos. 15 and 16 the leg is practically straight, although not yet making contact with the ground; and that at No. 18, when the heel makes contact with the ground, the knee is flexed 16 degrees.

2. *Ankle Movements.*—The maximum movement at the ankle is through 21·5 degrees, 9·5 degrees being towards the toe, and 12 degrees towards the heel.

TABLE.

FLEXION OF KNEE.			ANKLE MOVEMENT.		
From Straight.		*Flexion.*	*Angle Line of Lower Leg to Ankle makes with Line from Sole to Heel.*		
No.	*Degrees.*		*No.*	*Degrees.*	
1.	163	−17	1.	92·5	+ 2·5
2.	168	−12	2.	93·5	+ 3·5
3.	173	− 7	3.	95·5	+ 5·5
4.	179	− 1	4.	97·0	+ 7·0
5.	181	+ 1	5.	99·5	+ 9·5
6.	173, heel lifts	− 7	6.	89·5, heel lifts	− 0·5
7.	163	−17	7.	93·0	+ 3·0
8.	145	−35	8.	88·0	− 2·0
9.	124, toe lifts	−56	9.	82·5, toe lifts	− 7·5
10.	115	−65	10.	78·0	−12·0
11.	112	−68	11.	86·5	− 3·5
12.	123	−57	12.	87·5	− 2·5
13.	134	−46	13.	88·0	− 2·0
14.	155	−25	14.	85·0	− 5·0
15.	177	− 3	15.	85·0	− 5·0
16.	181	+ 1	16.	89·0	− 1·0
17.	171	− 9	17.	87·0	− 3·0
18.	164, heel contact	−16	18.	87·0, heel contact	− 3·0
19.	159, toe contact	−21	19.	87·0, toe contact	− 3·0
20.	157	−23	20.	91·0	+ 1·0
21.	160	−20	21.	93·0	+ 3·0

(*Signed*) HENRY LONGMATE, A.M.I.Mech.E.,
Superintendent Experimental Workshop,
Artificial Limb Section, M.O.P.



inch in this reduction.

[To face p. 170.

Analysis of Walking Movements.

The accompanying Cinematograph Chart No. 1 shows a series of successive positions of a human leg during ordinary walking, and was prepared from a cinematograph film of an uninjured man who walked in his usual manner on a wooden horizontal platform in front of a screen divided by white tapes into 10 cm. squares.

EXPERIMENTAL WORKSHOP, ARTIFICIAL LIMB SECTION, MINISTRY OF PENSIONS.

CINEMATOGRAPH CHART NO. 1.

Natural Walking on the Level (with Boots), One Complete Stride.

The accompanying table of the angles recorded on Cinematograph Chart No. 1 shows up the following salient points (see fig. 172):

1. *Flexion of the Knee.*—The maximum flexion with *toe in contact with ground* is 35 degrees (from the straight line of the leg—*i.e.*, 180 degrees). Immediately the toe leaves the ground (at No. 9) the flexion is nearly doubled, increasing to 68 degrees in the three following pictures.

It will be seen that at Nos. 15 and 16 the leg is practically straight, although not yet making contact with the ground; and that at No. 18, when the heel makes contact with the ground, the knee is flexed 16 degrees.

2. *Ankle Movements.*—The maximum movement at the ankle is through 21·5 degrees, 9·5 degrees being towards the toe, and 12 degrees towards the heel.

TABLE.

FLEXION OF KNEE.			ANKLE MOVEMENT.		
From Straight.		*Flexion.*	*Angle Line of Lower Leg to Ankle makes with Line from Sole to Heel.*		
No.	*Degrees.*		*No.*	*Degrees.*	
1.	163	−17	1.	92·5	+ 2·5
2.	168	−12	2.	93·5	+ 3·5
3.	173	− 7	3.	95·5	+ 5·5
4.	179	− 1	4.	97·0	+ 7·0
5.	181	+ 1	5.	99·5	+ 9·5
6.	173, heel lifts ..	− 7	6.	89·5, heel lifts ..	− 0·5
7.	163	−17	7.	93·0	+ 3·0
8.	145	−35	8.	88·0	− 2·0
9.	124, toe lifts ..	−56	9.	82·5, toe lifts.. ..	− 7·5
10.	115	−65	10.	78·0	−12·0
11.	112	−68	11.	86·5	− 3·5
12.	123	−57	12.	87·5	− 2·5
13.	134	−46	13.	88·0	− 2·0
14.	155	−25	14.	85·0	− 5·0
15.	177	− 3	15.	85·0	− 5·0
16.	181	+ 1	16.	89·0	− 1·0
17.	171	− 9	17.	87·0	− 3·0
18.	164, heel contact ..	−16	18.	87·0, heel contact ..	− 3·0
19.	159, toe contact ..	−21	19.	87·0, toe contact ..	− 3·0
20.	157	−23	20.	91·0	+ 1·0
21.	160	−20	21.	93·0	+ 3·0

(*Signed*) HENRY LONGMATE, A.M.I.Mech.E.,
Superintendent Experimental Workshop,
Artificial Limb Section, M.O.P.

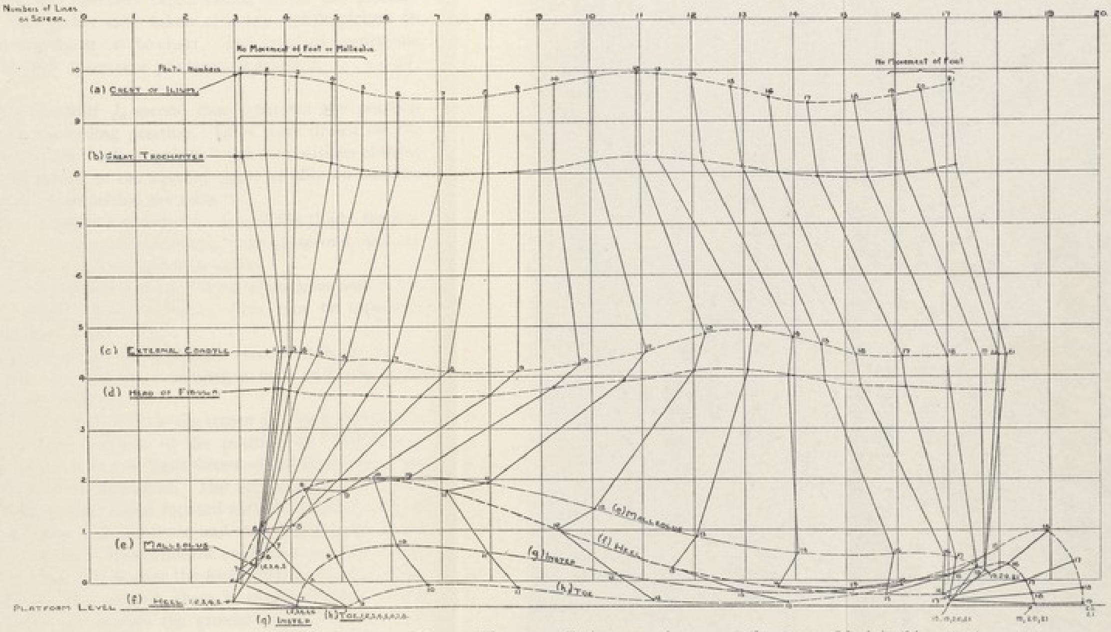


FIG. 172.—CINEMATOGRAPH CHART NO. 1: NORMAL WALKING. Each square of 10 cm. on the screen = ⅝ inch in this reduction.

[To face p. 170.

The man was naked except for boots and socks, and the "salient points" mentioned on the chart (the crest of the ilium, great trochanter, etc.) were marked on him by means of plaster discs.

The camera was specially rapid, taking about 160 pictures per second, and prints were taken of every eighth picture to complete the step shown on the chart. This required twenty-one prints, giving the successive positions, marked 1, 2, . . . 21, shown.

An interval of about $\frac{1}{20}$ second thus separates any position from the next succeeding position. Lines were drawn on the prints connecting the "salient points," and the positions of these lines were transferred to the squared paper readily on account of the squared screen behind the subject.

These lines obviously represent the line of the thigh, the line of the leg, etc., in successive positions every $\frac{1}{20}$ second, and are in correct relative position as regards space.

It will be seen that the maximum bend of the knee and of the ankle, and various other important facts, can be measured directly from the chart.

In considering these cinematograph records it is to be remembered that the subject is wearing a boot with the usual 1 inch heel and $\frac{1}{2}$ inch sole.

When the film is projected on the screen at a very slow speed, the subject is seen standing in the position of "attention." The first movement visible is slight flexion of the knee of the limb which is about to be advanced. The heel still resting on the ground, the pelvis next comes forward with the superincumbent trunk, and the knee is straightened and then flexed more as the heel leaves the ground. Meanwhile the ankle becomes more dorsiflexed, but becomes less so after the *heel* leaves the ground until, as the *toe* leaves the ground, there is plantar flexion, which persists till the heel reaches the ground again, when it gives place to slight dorsiflexion. At this stage the toe-joint is extended so that the toe descends in a curve not far from the vertical.

The hip during this stride follows a wave-like curve, with its first trough just as the heel leaves the ground, and its second just as it reaches it again, the crest of the wave being midway between these two phases, but not corresponding to the time of maximum knee flexion.

As the toe leaves the ground the knee is flexed 35 degrees (145 degrees). This flexion increases as the knee comes forward (with the toe in the air) till it reaches 68 degrees (112 degrees).

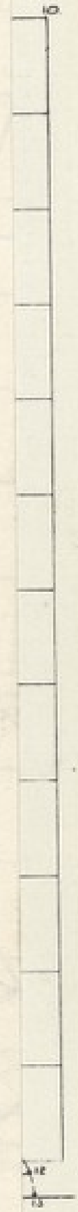
Just before the heel is set down the knee is practically straight, but it is flexed again, so that when the heel makes contact with the ground the knee is flexed to 16 degrees (164 degrees). The maximum ankle movement is 21 degrees, 9 degrees dorsiflexion and 12 degrees plantar.

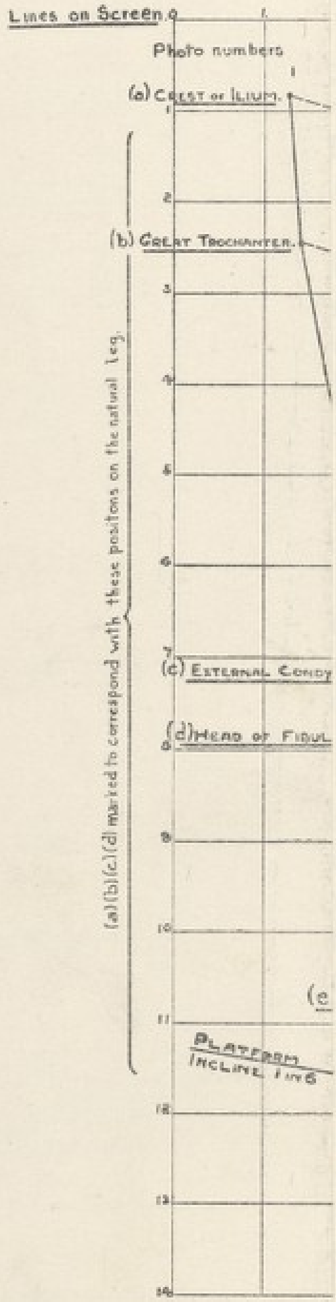
It is of interest to note that the angle between the line joining the great trochanter and the external condyle, on the one part, and that joining the external condyle and the head of the fibula varies in the diagram with varying degrees of knee flexion, due to the normal rotation of the tibia round a transverse axis through its head.

In the artificial limb diagram, of course, this is not seen, movement at the knee being a simple rotation around one fixed axis.

The diagrams of gait with an artificial limb were prepared from films taken of a subject having an amputation in the middle of the thigh, walking with a prosthesis fitted with central knee control, as described in Chapter XIV., on the Mechanics of Prostheses for the Lower Limbs.

Cinematograph Charts Nos. 2 and 3, illustrating the gait with a thigh prosthesis, were taken under conditions similar to those under which No. 1 was taken, but the observation points below the hip were placed at spots estimated to correspond to the anatomical points upon the natural limb. In Chart No. 2 only thirteen positions of the artificial limb are shown. It is to be noted that the crest of the ilium only moved forward 0·4125 metre horizontally in space. In Chart No. 1 it will be seen that the first thirteen positions of the natural limb covered 0·825 metre. It appears, therefore, that the rate of progress with the artificial limb was only about half that with natural limbs. Allowing for this reduction of the horizontal scale, the differences between the Charts 1 and 2 are not great. The heel of the artificial foot leaves the ground sooner than does that of the natural gait. This is probably due to the restricted range of ankle movement in this type of leg. In Nos. 9 and 10 of No. 2 Chart the knee is checked temporarily, but in no phase does it go backwards in space as does the knee in the chart of du Bois Reymond. The prosthesis used was one with shoulder control of knee move-





Lines on Screen
Photo numbers
(a) Crest of Ilium.
(b) Great Trochanter.
(c) External Condy
(d) Head of Fibul
(e
Platform
Incline 1 in 6
(a)(b)(c)(d) marked to correspond with these positions on the natural leg.

Fi

ments, auxiliary elastic knee extension, and rubber buffer ankle action.

The chief outcome of a comparison of these charts is the evidence of how nearly the gait of a well-trained walker with a

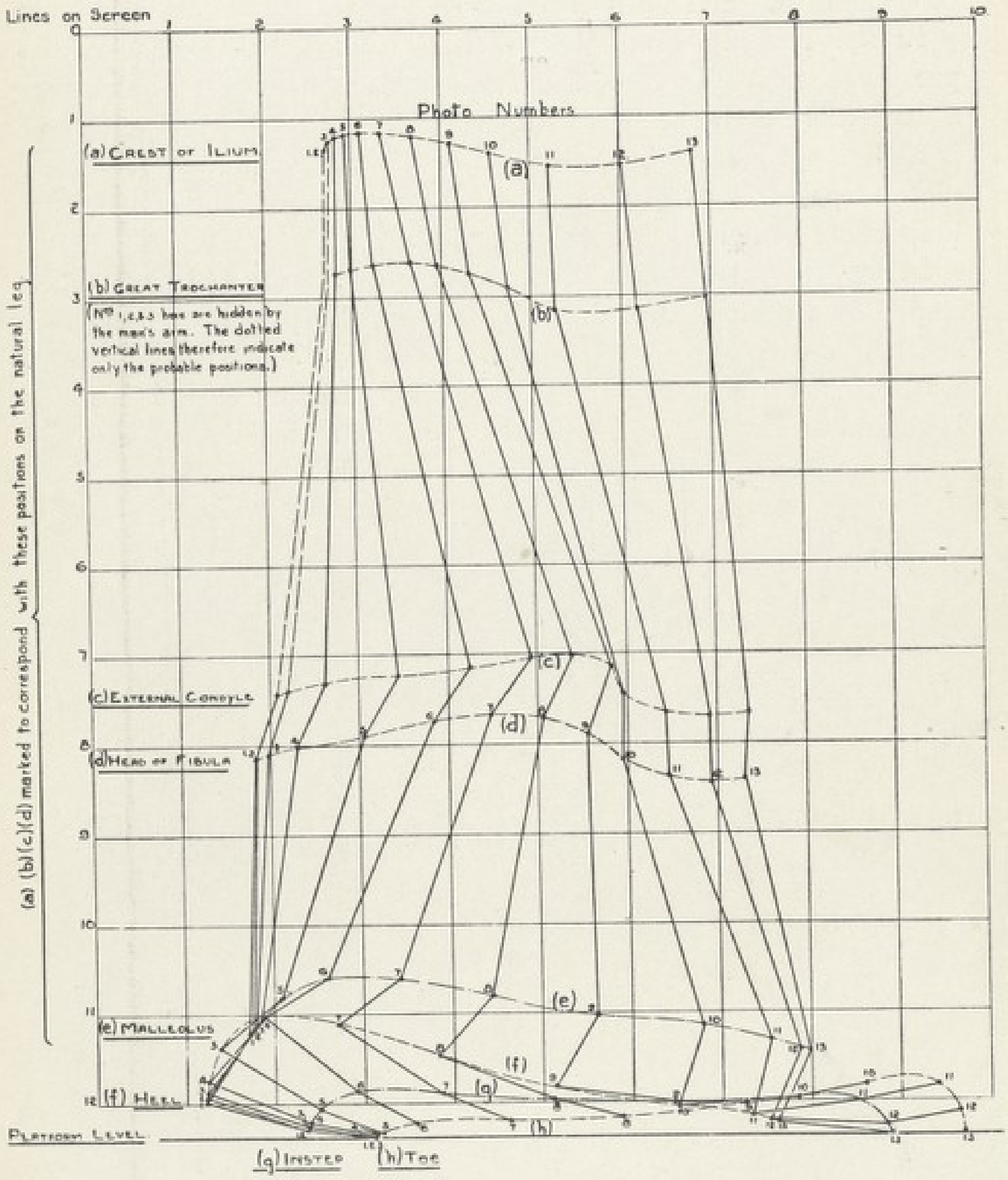


FIG. 173.—CINEMATOGRAPH CHART NO. 2: WALKING WITH AN ARTIFICIAL LIMB ON THE LEVEL.
Amputation in right thigh; stump 11 inches long.

proper prosthesis approaches to the normal. In Chart No. 3, showing walking with a prosthesis down a slope of 1 in 6, the effect of the help of gravity is seen, which minimizes efforts of

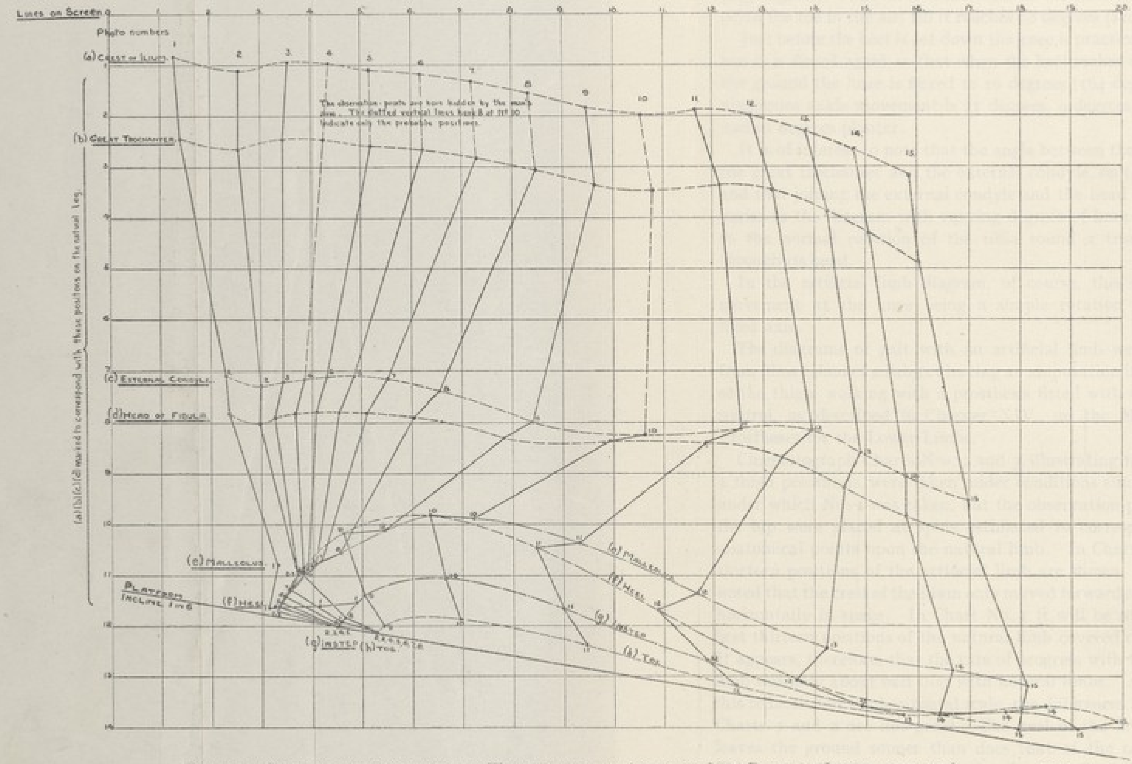


FIG. 174.—CINEMATOGRAPH CHART NO. 3: WALKING WITH AN ARTIFICIAL LIMB DOWN AN INCLINE OF 1 IN 6. [*To face p.* 173.

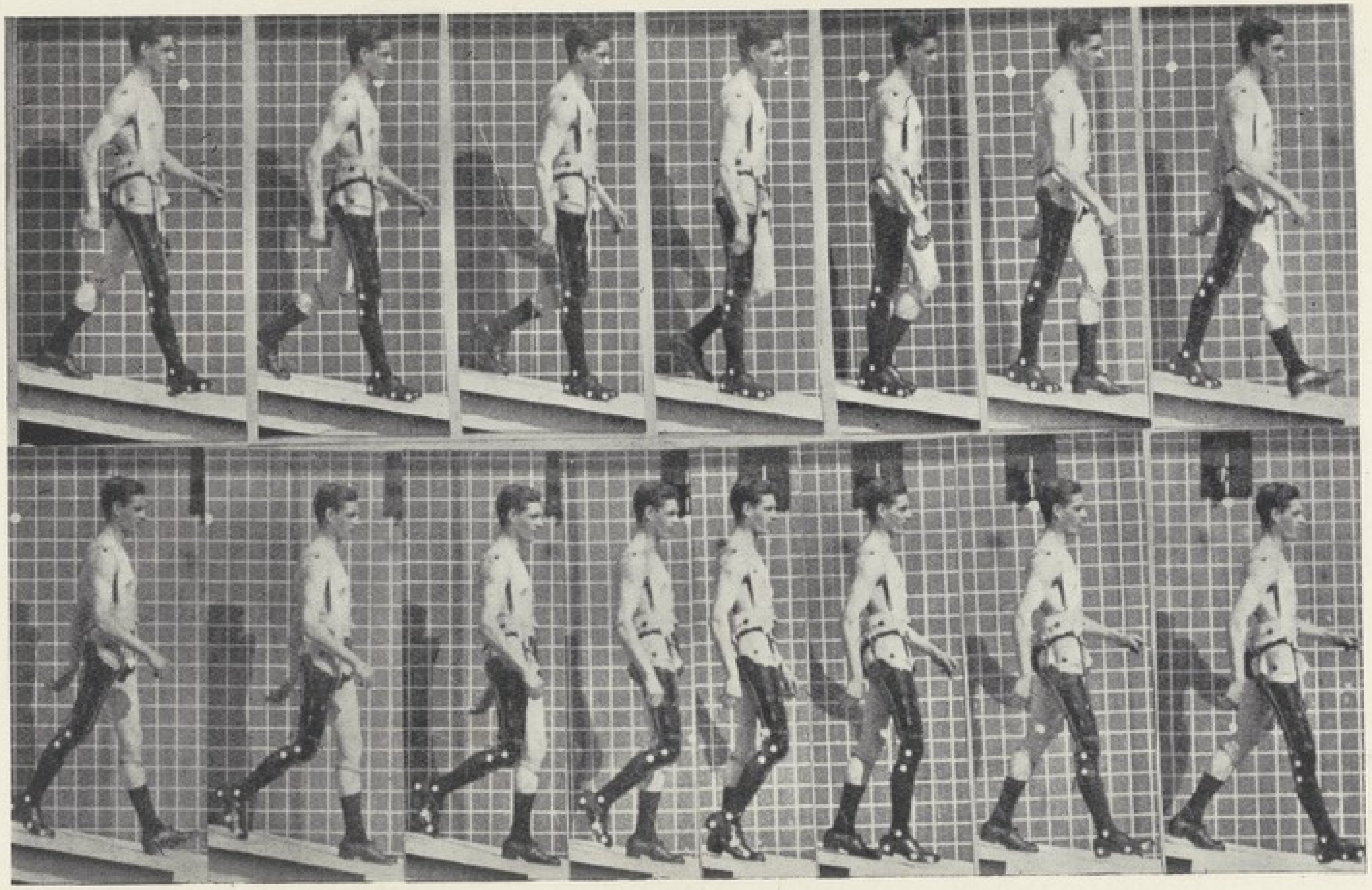


Fig. 177.

[To face p. 174.

propulsion. The walk is much quicker, and there is no tendency to checking of the knee movement about positions 9 and 10.

The accompanying four plates, figs. 175 to 178, have been made from enlargements from exposures selected at regular intervals from the length of film used.

In fig. 175 the subject is starting from "attention," the prosthesis next the camera. These fifteen photographs show a little more than one step with the right leg.

In fig. 176, taken in the course of a walk, nearly two complete steps of eight photographs each are shown, the natural limb being next the camera.

In fig. 177, also taken in the course of a walk, two whole steps down a slope of 1 in 6 are shown, the prosthesis being next the camera.

In fig. 178 the same subject is shown jumping over a box. It should be noted that he alights upon the artificial foot, with his whole weight and impetus upon it and the stump.

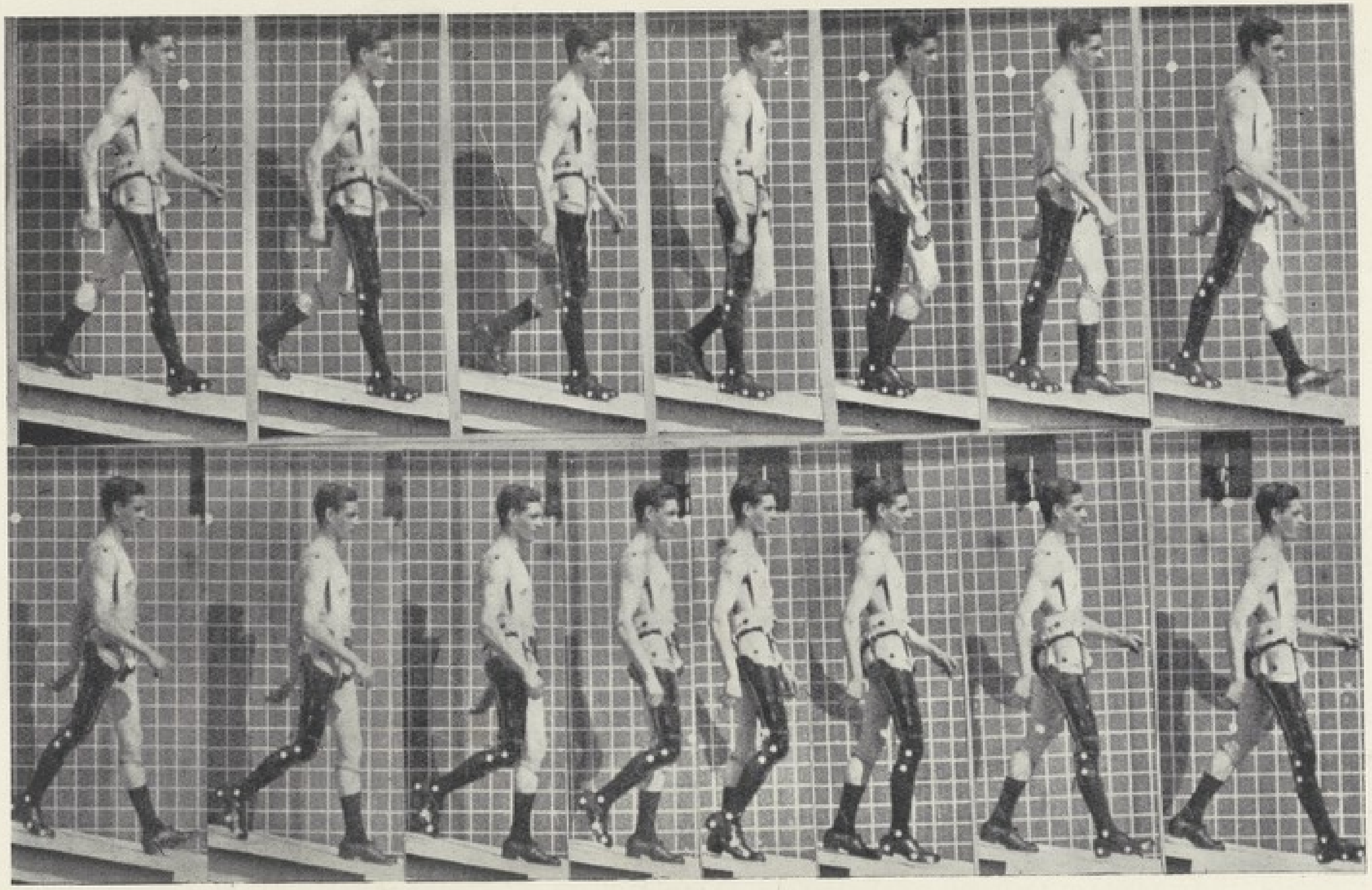
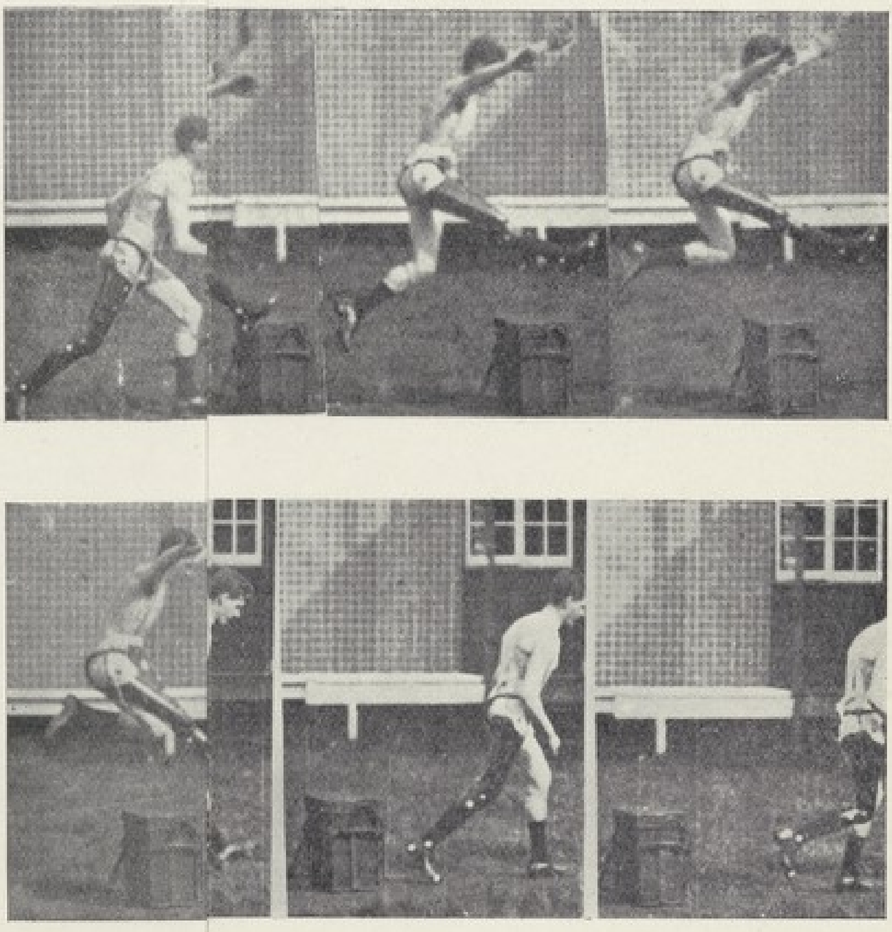


Fig. 177.

[To face p. 174.



[*To face p.* 174.

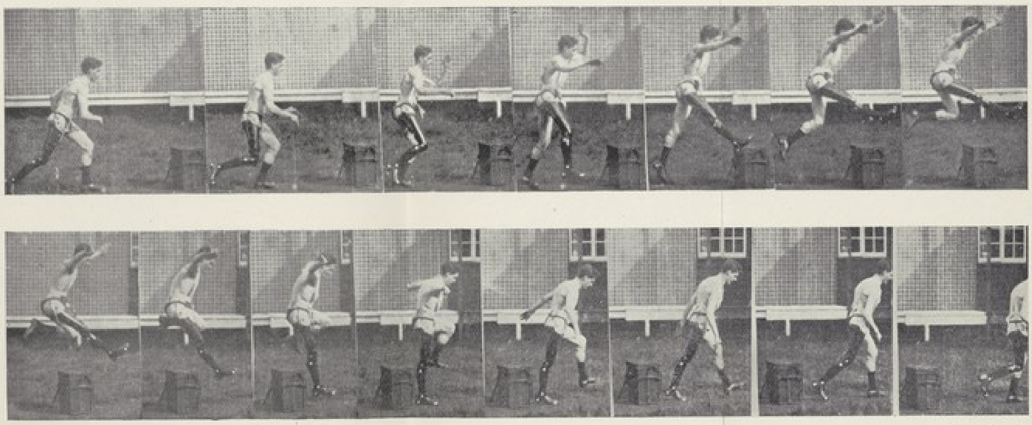


Fig. 178.

[*To face p.* 174.

CHAPTER XIV

THE MECHANICS OF PROSTHESES FOR THE LOWER LIMBS

HOWEVER cunningly devised and constructed an artificial leg may be, the fact that its wearer has lost the muscles or muscular insertions by which the amputated segments were controlled makes its use a very different matter from that of the living limb. In the case of amputation through the shaft of the femur, the power of moving the thigh portion of the prosthesis remains, and is the more efficient the longer the segment of the bone remaining. The question of the muscular power of thigh stumps of various lengths has been investigated by Mommsen,[1] and the relative muscular value of stumps of various lengths may be estimated from the annexed figures. It is to be borne in mind, however, that in many stumps the muscles acquire new attachments, and that therefore there may be a much better musculature than a consideration of the figures alone would suggest.

Dr. Mommsen sought to analyze the influence of the height of amputation on the muscular action by the help of the exact researches of Roith. In fig. 179 are shown the relative insertions of the extensors and flexors, and in fig. 180 those of the adductors and abductors of the hip. The continuous lines represent the distal insertions which act on the hip-joint under favourable mechanical conditions. The dotted lines show the insertions of those muscular fibres which, according to the investigations of Roith, act under relatively unfavourable mechanical conditions. As to flexion and extension, there are three muscles in front and three behind inserted into the tibia, which nearly balance one another. Higher up, the long fibres of the adductor longus, the short fibres of the adductor brevis, and the anterior

[1] See Mommsen, "Muskelphysiologie des oberschenkelstümpfes," *Münchener Medizinische Wochenschrift*, 1918, No. 45; and abstract in the *Medical Supplement, Daily Review of the Foreign Press*, vol. ii., No. 4. p. 153.

fibres of the glutæus act on the hip-joint under relatively unfavourable conditions, and the only true hip flexor is the ilio-psoas.

The flexor muscles of the hip-joint have their insertions relatively higher than the extensors, as the glutæus maximus is not an extensor under ordinary conditions. In an exarticulation at the knee-joint both extensors and flexors lose their insertions, but the balance of power is not affected. In an amputation between the lower and middle, or between the middle and upper thirds of the femur, the flexors are much less weakened than the extensors. There are two kinds of hip extension:

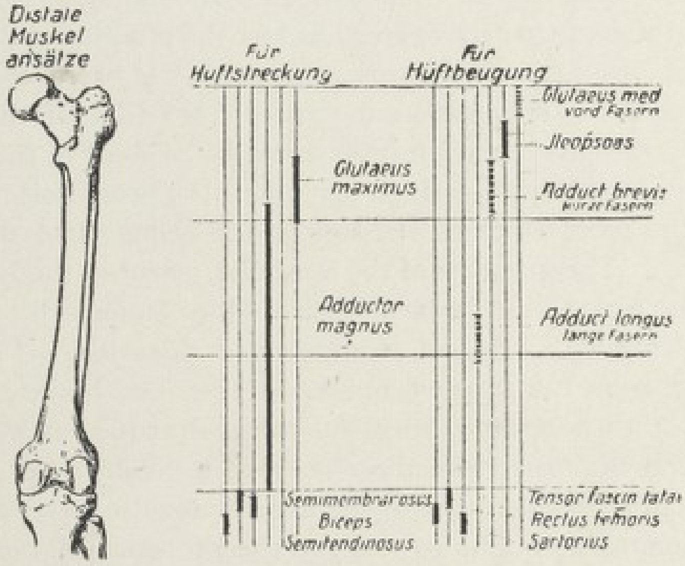


FIG. 179.—DIAGRAM OF THIGH-STUMP MUSCLES (MOMMSEN). Extensors and Flexors.

1. By the posterior part of the adductors and the hamstrings.

2. By the combined action of the adductors and the glutæus maximus.

The usual kind in the erect position and ordinary gait on level ground is the first named. The second kind, according to Mommsen's researches, acts only when the following three conditions are simultaneously fulfilled:

1. If the knee-joint is somewhat flexed.

2. If the suprafemoral centre of gravity of the body falls in front of the common axis of the hip-joint.

3. If the extensors prevent further flexion of the knee and hip the above is true for normal limbs, but without these conditions Mommsen has proved by repeated examinations that the

glutæus maximus does act in walking on level ground, but not in short stumps.

The relative heights of insertion of the flexors and extensors account for the prevalence of flexion contracture of the hip. This weakness of the flexors makes it necessary to set the knee-joint as far back as possible, in order to prevent the knee from yielding forwards in walking. In an artificial limb the lines joining the situation of the tuber ischii with the knee-joint, and that joining the knee-joint to the ankle-joint, should form an angle open in front; for short stumps this angle should be 177 to 178 degrees.

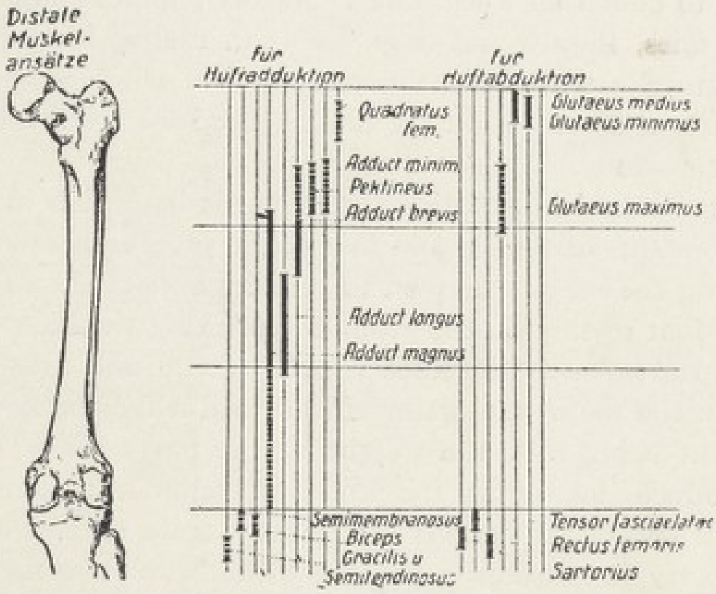


FIG. 180.—DIAGRAM OF THIGH-STUMP MUSCLES (MOMMSEN). Adductors and Abductors.

In prostheses for very short stumps elastic extension at the hip-joint is a very great help.

As regards adduction and abduction, when the amputation is above the knee-joint the two groups of muscles are fairly balanced if the bone section is below the middle of the femur, but as we ascend above that point the abductors have an increasing advantage. To assist and maintain adduction it is necessary to tighten the suspenders over the sound shoulder. The nature of the alterations in the form of the stump which are caused by muscle atrophy depend largely on the height of the site of amputation. If the site is such that the adductors and hamstring muscles are still active, it will be found difficult or impossible to give a broad support directly under the tuber ischii. When, however, those muscles are no longer effective, it is possible so to shape the top of the socket that it is bowed sharply inwards under the tuber, and affords a broad horizontal support to that bone. This formation of the socket (*Reitsitz*, riding seat) has the additional advantage that it brings the point of support farther outwards under the affected side of the pelvis, and thereby tends to counteract the drooping of the right hip or apparent Trendelenburg phenomenon.

No matter what may be the muscular power over the thigh, control over the knee and the foot is lost. Even if it were feasible to construct knee, ankle, and foot joints similar to the natural ones, they would be worse than useless in the absence of the muscles which control them, and of whose co-ordinated and constant action when the limb is used we are for the most part unconscious.

It is necessary to examine the methods by which in walking the movements of the leg and foot of the prosthesis are effected. Supposing the leg or shin part to be fully extended on the thigh and the foot resting on the ground, on flexing the hip by means of stump movement the knee will be raised, and first the heel and then the toe of the artificial limb will leave the floor. The knee-joint being free, the weight of the parts below the knee will produce flexion at the knee. Pendulum action, or the action of springs of various kinds, may again extend the knee, but if active extension is necessary there are two methods of achieving it. One is by the use of knee control cords or straps, which will be described later; in the other method the desired movement is effected by extension of the hip and backward pressure of the stump. This is only possible when the foot is fixed, as by contact with the ground. In the diagram (fig. 181) the three arrows show the main forces concerned. The end of the stump pressing backwards tends to push the knee-joint in the like direction. The foot, however, is fixed upon the floor, and the weight of the trunk opposes a resistance to the movement of the upper end of the thigh lever backwards, and its momentum also helps. The effect of pushing back the knee, then, is to extend that joint. At the same time the hip is raised and downward pressure of the foot upon the floor is increased.

In this way the wearer of a prosthesis who is about to put his weight upon it is able to obtain firm support. Similarly, if in walking when the limb is loaded the knee begins to flex, backward pressure of the stump stops the movement and restores stability. This method of effecting knee extension may be enough in the case of a long stump, but it is obvious that the shorter the stump the greater the disadvantage at which the force is applied, so that in very short stumps control over the knee is but feeble. During the last few years the method of central knee control has been used more and more in this country by limb makers, and has been adopted as the standard by the

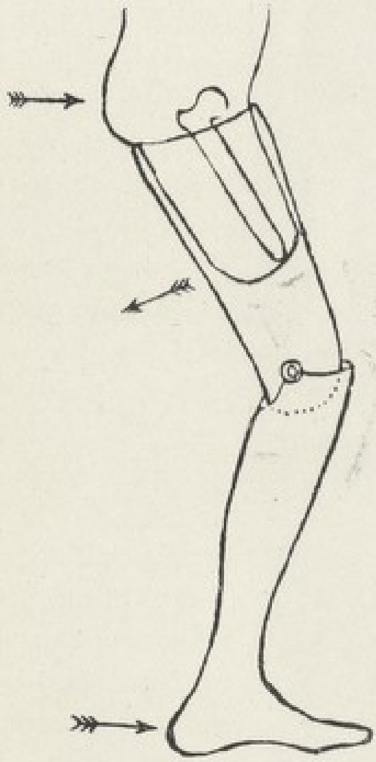


Fig. 181.

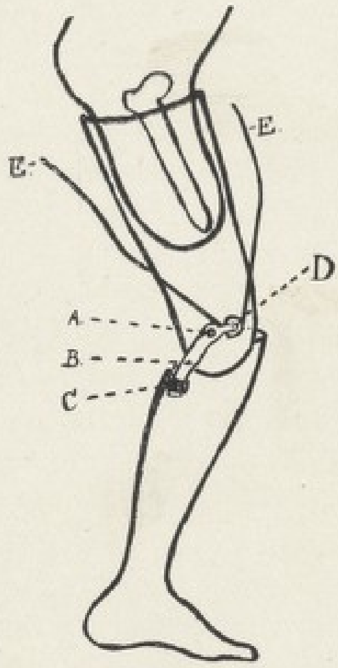


Fig. 182.—Diagram of the Standard Limb for Above Knee Amputation.

Ministry of Pensions in agreement with the British Limb Makers' Association. Different makers have had different ways of applying the method, but the principle is the same, and is represented diagrammatically in fig. 182.

The diagram represents a fore-and-aft section of the knee-joint, in which the knee bolt (A) passes through the knee lever (B), the lower end of which is fixed in the staple (C) inside and at the back of the shin piece. At the upper end of B is the roller (D) round which the roller cord (E, E) passes.

There are two of these cords, a right and a left, only one of which is represented in the diagram. The upper ends of the cords are connected at back and front with the suspenders, of which one passes over each shoulder. When the wearer stoops the cords are slackened, and when he straightens his back and throws back his shoulders the cords are tightened and their

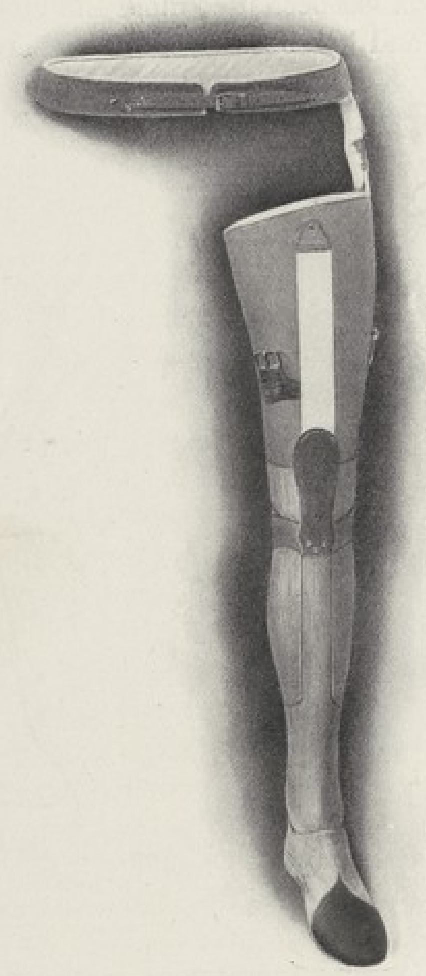


FIG. 183.—ERNST'S PATELLA AND ELASTIC EXTENSION.

traction upon the roller, acting through the knee lever upon the shin piece, causes extension of the knee. With practice this action becomes automatic, so that without conscious attention the shoulders are thrown back directly the wearer feels that his knee is beginning to flex unduly, or when going down steps or on a slope it is necessary to maintain extension of the knee.

The knee lever also acts as part of the stop which prevents over-extension of the knee. In full extension its anterior surface is pressed against the knee buffer in the front part of the slot in the knee piece.

Despite the safeguard against falls afforded by the shoulder braces and knee control of the American type of limb, which undoubtedly enable an amputee who is used to the method to recover from a stumble, some patients have complained of the irksomeness and constraint of the shoulder braces, and welcome any arrangement which enables them to do without it.

The light metal limb with rather stiff knee-joints and pelvic band dispenses with the shoulder control, and has only one webbing strap over one shoulder, which holds up the belt after the manner of the Sam Browne sword belt. Even this strap may in some cases be dispensed with.

The older prostheses of thigh amputations had spring extension of the knee, of which one of the drawbacks is that it is always in action while the knee is flexed, and, if powerful, will cause the leg to kick out when the wearer is sitting down unless the foot is pressed upon the ground.

This spring may be a spiral one of steel inside the shin piece, or a strip of strong elastic webbing in front of the knee, attached below to a piece of leather called an artificial patella, and above to suspenders or to the upper part of the thigh socket. In some cases both kinds of spring are used in the same prosthesis. This pattern is still preferred by some amputees (see fig. 183).

In the Hanger leg, one of the most widely used types, which is adopted by the Belgian Government, an ingenious arrangement of a wooden knee lever and elastic webbing concealed inside the shin piece affords an adjustable extending force, which aids the active shoulder control (see fig. 184).

The forked upper end of this lever is pivoted upon a pin placed in the knee piece behind the knee bolt. The lower end of the lever is fastened to the lower end of a stout piece of elastic webbing, which runs upwards to be attached by a leather thong to the back of the shin piece about 2 inches below its upper edge. The tension of the elastic is regulated by the tightness with which this thong is tied. When the knee is flexed to a right angle, the line of upward pressure of the elastic on the lever passes through the pivot and the centre of the knee bolt, and has then no turning effect, the mechanism being at a " dead centre."

But when the knee is flexed to less than a right angle, the stretched elastic exerts an extending force on the knee by pushing the knee lever upwards in a manner similar to that of the connecting rod of a steam engine on the crank axle, the elastic representing the propelling force of the steam in the cylinder. This knee lever also serves as part of the stop which prevents over-extension of the knee.

The movements of the natural ankle, taken together with those of the tarsal joints, are flexion-extension, ab- and adduction, and rotation outwards (varus) and inwards (valgus). Abduction is normally accompanied by rotation inwards and adduction by

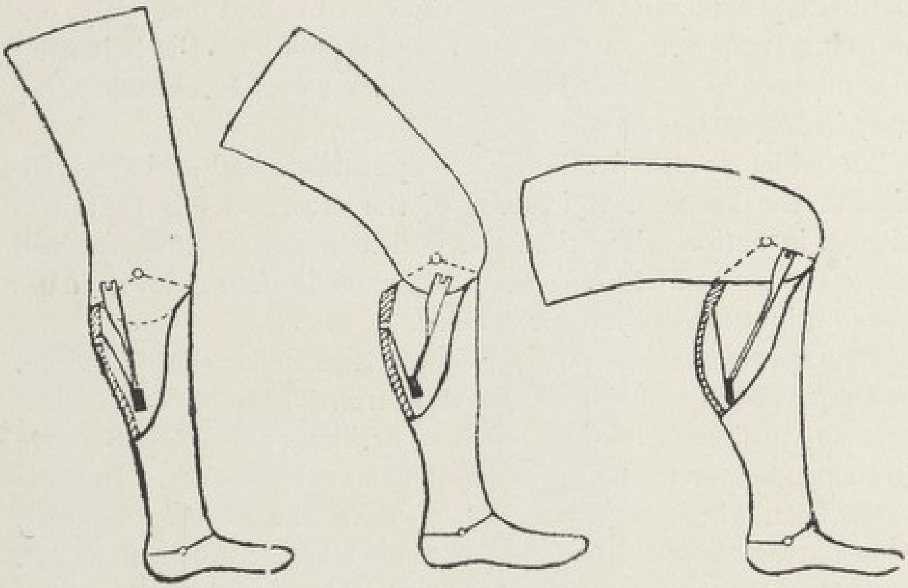
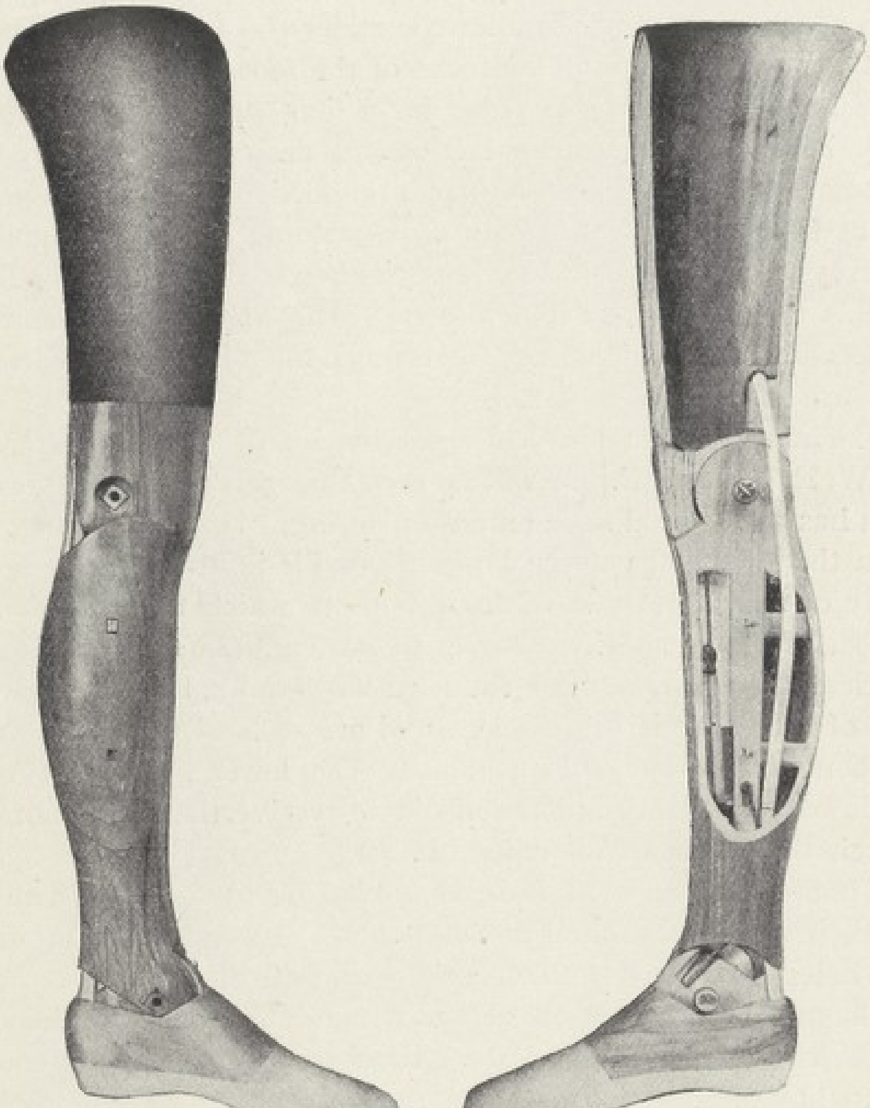


FIG. 184.

rotation outwards. These movements, which are very free, are of great value in the normal foot when controlled by the action of the powerful muscles the tendons of which pass over the ankle. Artificial feet are made which allow of a rotation movement on a horizontal antero-posterior axis, placed in a position approximated to that of the medio-tarsal joint, but with extremely few exceptions surgeons and limb makers are agreed that there is no advantage to be gained by this practice. One or two makers prefer to do without any ankle-joint, relying on a flexible foot and toe-joint or the rocker action of a curved sole for the necessary resiliency. The older British practice has been to articulate the foot with the shin piece by means of a wooden mortice and tenon, through which a steel bolt passes horizontally at a level corresponding to the tip of the internal malleolus of the sound limb. It is a matter of indifference whether the tenon be part of the shin piece or of the foot. In what has been known as the clapper foot movement is checked in both directions by the interposition of spiral steel springs at the heel and the front of the ankle. In



A B

FIG. 185.—ANGLESEY LEG.

A. Side view of limb for amputation above knee. B. Section of limb showing details of construction.

the so-called Anglesey leg, which was introduced as an improvement in or about the middle of the last century, the anterior spring is dispensed with, and the foot is prevented from dorsiflexing too far by an inelastic cord, usually of catgut, which is securely fastened to the back of the knee above, and, passing through the hollow shin piece, is fixed to the back of the heel of the artificial foot. The length of this cord, or tendon as it is generally called, is adjusted so that when the knee is extended the foot is in a position of talipes equinus at about 100 degrees, and when the knee is fully bent dorsiflexion some 5 degrees beyond the right angle is allowed, under the action of the heel spring or of pressure of the front of the foot upon the ground. This method has been popular for a long time, but against it may be urged the fact that it is not desirable invariably to associate knee extension with plantar flexion, and that a very slight stretching of the tendon or yielding of its attachment destroys the action, and that this yielding is the rule after a few week's use (see fig. 185, A and B). The Anglesey leg has the great advantage of lightness, and is much liked by those amputees who are accustomed to it.

The annexed figures show the mechanism of this limb as made by W. R. Grossmith. It will be seen that this particular specimen has an internal knee extension spring.

In the standard pattern limbs the ankle-joint consists essentially of a transverse steel ankle bolt, to which two steel bolts are rigidly fixed at right angles to its length. The bolts pass vertically upwards through the hard wood ankle base and lower end of the shin piece or socket, and are secured with nuts and washers inside it (see Appendix). The lower surface of the ankle base is suitably hollowed out to receive the lower half of the circumference of the ankle bolt.

The foot is connected with the ankle base by means of a steel staple which passes round the ankle bolt. Its ends pass through two holes in the foot, to be secured with nuts on the sole.

The amount of ankle movement is regulated by the resiliency of the rubber buffers, and the extent to which they are compressed by tightening the nuts on the staple in the sole.

This kind of ankle-joint allows generally of less movement than the clapper or the Anglesey patterns, but it gives more security, combined with elasticity of gait.

In some patterns the hollow for the heel buffer is carried right through the wood of the foot, so that the rubber protrudes, but is prevented from escaping by a strong piece of soft leather fixed over the opening. By this means any jar on the heel is absorbed by the rubber buffer, through which upward pressure on the heel is transmitted without the interposition of the wood of the foot. It may be questioned whether any advantage is gained by this arrangement, as the main weight of the body

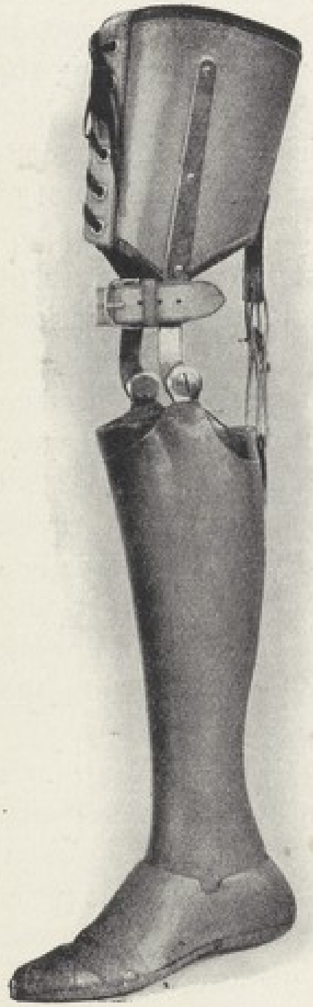


FIG. 186.—GROSSMITH No. 8 LIMB.

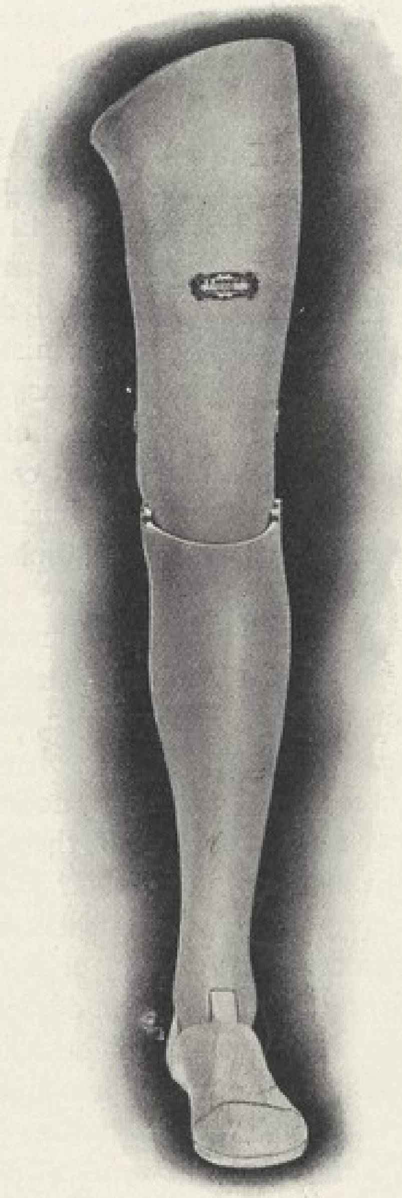


FIG. 187.—GROSSMITH ANGLESEY LEG WITH MORTICE AND TENON ANKLE-JOINT.

must be transmitted through the ankle bolt, the leather bushing, and the sole of the foot.

Ball bearings for the metallic joints of prostheses are used by some manufacturers. The idea is an attractive one because ball bearings are well known, and it is recognized by the public that they save a great deal of friction and useless expenditure of energy in the case of bicycles and other machines. But the cases of such machines and of prostheses are very different. In the case of a bicycle wheel which is revolving many times in a minute there is a great advantage in ball bearings. The joint of a prosthesis, on the other hand, in no case is subject to a complete revolution or to fast motion. The movements are slow and of small range; probably no joint moves through an angle of more than 30 degrees in ordinary locomotion. The sole real advantage of these joints is their adjustability. To a certain extent the wear of the joint can be taken up by tightening the screw cone or replacing worn balls by new ones.

For these reasons the Ministry of Pensions, with the concurrence of engineers, surgeons, and limb makers, decided not to use ball bearings in the joints of standard limbs.

It has long been the practice of the best limb makers to fit brass or phosphor-bronze bushes in steel joints in situations where leather bushes are inapplicable.

Broadly speaking, there are two kinds of steel joints used in all sorts of prosthetic appliances. The simplest and cheapest is the lap-joint, which consists essentially of one piece of steel overlapping another, with a screw or bolt passing through perforations in both. The bolt is prevented from turning in one of the steels, with which it moves as if it formed part of it, and the other steel moves upon the bolt. These lap-joints are weak and do not wear well; their stability depends entirely on the bolt or screw which draws them together.

The mortice and tenon, or male and female joint, is a much more efficient mechanical device, which is almost universally used in the best work. The female part or fork is cut out of solid metal with a milling machine or other tool. The male part, which fits accurately between the jaws of the fork, is bored with a perforation larger than those in the latter, so as to leave room for a bush, which consists of a ring of phosphor-bronze on which the bolt or screw, which is fixed to the fork, turns. If the joint is properly mounted and not exposed to improper lateral strains, the wear will come chiefly upon the screw, and the faces of the mortice and tenon will last for a long time without serious deformation.

The bush and the screw are both easily removed and replaced when worn.

All complete prostheses for the lower extremity represent attempts to imitate the lost member not only as a means of support and locomotion, but also by providing ornamental parts for the sake of appearances and movable joints to take the place of the natural ones and to allow the normal movements, as far as these are possible and consistent with the maintenance of stability.

It must be remembered that, looked at as a complete whole, any articulation in a limb consists of much more than the osseo-cartilaginous, synovial, and ligamentous parts, for the muscles and their tendons which pass over the joints play a most important rôle in regulating and limiting, as well as causing, the movements of the bones, and that without their aid and support the usual physiological functions of the joints could not be carried out.

Unfortunately, in prostheses the muscles cannot be reproduced, and the elastic accumulators, which are sometimes called "artificial muscles," are really only artificial elastic ligaments, fulfilling functions analogous to those of the ligamentum nuchæ in ruminants.

For these reasons it is not advisable to provide for all the normal movements in artificial hip or ankle joints, because the muscles that should control those movements are wanting, and although makers of prostheses have from time to time devised and advocated such joints, they have not been generally adopted.

In the Bly leg, which is described in the historical section of this work, an attempt was made to represent the five principal muscles of which the tendons pass over the ankle-joint, but although this limb was highly spoken of by H. H. Bigg, it has fallen into disuse and oblivion. In some of the feet made in the present day there is an additional joint with an antero-posterior horizontal axis placed in front of the usual transverse ankle-joint. This joint allows rotation of the foot, and is intended to represent the movement of the natural astragalo-scaphoid joint. Dr. F. Martin of La Panne, in his monograph, "La Prothèse du Membre Inférieur," published in 1918, strongly advocates a similar mobility.

It is argued plausibly enough that it must be an advantage to accommodate the sole of the artificial foot to obliquities of ground level, as in walking on a sloping sidewalk, and that, in the absence of this adaptability, undue strain is thrown upon the stump, but this advantage is in practice found to be outbalanced by the grave disadvantage of insecurity. Patients whose ankle-joints have accidentally become loose so as to allow of this lateral angular movement generally complain of it and ask to have it done away with.

On the other hand, some limbs without any ankle-joint movement have been, and are, popular, and many patients walk well with them.

The advantage of a stiff, or relatively stiff, ankle is found in the support which is afforded by the front of the foot in walking when the opposite limb comes forward, and which enables the artificial limb to be used as a means of propulsion from the toe when in its most backward position. The same object is aimed at in the Anglesey tendon leg, which was therefore a great advance upon the clapper leg. A considerable degree of freedom of movement in the ankle is no doubt useful in going up and down steep hills, but this advantage can only be gained by the sacrifice of a certain amount of security.

In an above knee limb, when the ankle-joint mechanism allows too much dorsiflexion, it will sometimes be noticed that there is an unsightly eversion of the foot after the heel is placed upon the ground and before the toe comes down into contact with it. When this occurs, patients generally will complain of it because of its ugly look and a sense of insecurity. It is easily corrected by what is called "increasing the resistance in front of the ankle"—that is to say, by reducing the range of dorsiflexion, by increasing the thickness of the instep rubber buffer, or, in the case of a tendon leg, by tightening the heel tendon.

This tendency to rotate out the prosthesis is not due to the shape of the top of the socket, which, as already stated, often produces inward rotation when weight is put upon it, but is more probably due to the preponderance of external rotators among the extensor muscles of the stump, which are in action as soon as the heel comes down upon the ground. If there is enough resistance in front of the ankle to hold the foot slightly in the equinus position, the toe comes down upon the ground so soon after the heel as to prevent the outward twist of the limb.

Alignment of the Above Knee Leg.

The relative positions to one another of the segments of an above knee limb are important, and care has to be exercised in assembling the parts accordingly. This is often called the "alignment of the limb."

The foot and ankle-joint are connected with the shin piece in such a position that the foot is everted 5 degrees—that is to say, that the outer end of the ankle bolt is placed a little farther forward *on the foot* than the inner end, and the leather bushing and holes for the ankle staple are disposed accordingly. The heel should not project too far backwards beyond the back of the ankle base. The ankle bolt should be placed transversely under the middle line of the shin piece, so that in the erect position it shall be vertically under the knee bolt and its axis parallel to it. Some makers prefer to place the ankle-joint farther forward, and at an angle with the knee bolt, but the practice appears disadvantageous.

The position of the knee bolt in the knee piece has been already determined as well behind the centre line of the thigh segment of the limb. The side steels attached to the shin piece into the upper ends of which the knee bolt is screwed, however, are attached on the middle (transverse vertical) plane of the shin piece. Consequently, when the joint and the attached segments of the prosthesis are assembled, a continuation vertically downwards of the front line of the thigh segment will fall clear in front of the shin. Extension of the knee being limited by the thigh buffer or, in certain types, by knee check cords, these are so arranged as to allow slight hyperextension so that in the erect position the vertical line through the centre of gravity of the trunk shall fall well in front of the knee bolt, thus conducing to stability.

If it be necessary to reduce the hyperextension, it is easily done by thickening the buffer or tightening the check cord.

It is obvious that the farther back the knee bolt is placed, the less the danger of the knee giving way forwards under the weight of the body. If, however, it is placed too far back, the gait with a short thigh stump is apt to be stiff, owing to difficulty in flexing the knee.

The position of the hip-joint of a pelvic band in an above knee leg has already been discussed. The *alignment* of an artificial joint which overlies a natural joint is, however, of little importance in this connection, as stability is determined by the latter. In the case of a prosthesis for a hip-joint amputation the position of the hip-joint is important, and will be discussed in the section dealing with the No. 1 limb.

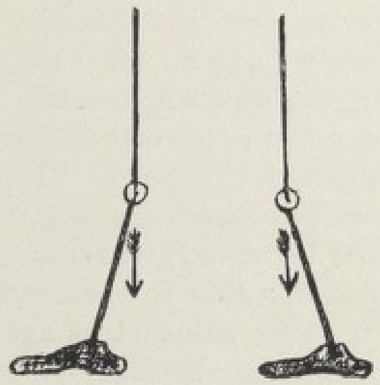


FIG. 188.

In this diagram it is assumed that no movement at the ankle is possible. The arrows represent the direction of the force of gravity, transmitted through the knee-joint. In A this force tends still further to *extend* the knee, but in B it tends to *flex* that joint.

The size and disposition of the rubber buffers at the heel and instep have important relations with the control of the knee-joint of an above knee prosthesis. If they are so arranged as to allow too easy dorsiflexion, as in B, the upper end of the shin piece comes forward, and the knee is encouraged to yield. If, on the other hand, there is much resistance in the heel and the foot is held in plantar flexion, as in A, when the sole is flat on the ground the upper end of the shin piece goes back and extension of the knee is encouraged. A similar effect is seen in children who have walked for some time with uncured talipes equinus in whom hyperextension (genu recurvatum) is a common symptom. The annexed diagrams may make the *modus operandi* more clear (see fig. 188).

A properly shaped socket will fit the stump correctly in one position, and one only. If it is twisted or otherwise shifted from this position it will not be comfortable.

Therefore adjustments intended to produce more eversion or inversion, etc., after the limb is assembled must be made by altering the relation between the socket and the parts below it. This can only be done by detaching the socket from the parts below and fixing it to the knee-piece or shin-piece (as the case may be) in a new position, after any necessary modifications of the opposed surfaces have been carried out.

That peculiarity of gait with an above knee prosthesis, which is known as double action of the knee, sometimes gives trouble.

It is not always easy to determine which of several possible causes is responsible for it.

This phenomenon is the result of extension of the knee being divided into two distinct phases. As the trunk comes forward on the prosthesis, the foot of which is on the ground, extension is nearly effected in one continuous movement, all but a very few degrees. There is then a momentary check to the movement of the joint, which is soon overcome with a slight but unpleasant jerk. An occasional cause of double knee action is too much resistance at the back of the ankle-joint—*i.e.*, that the heel rubber is too large. In that case, as the heel is placed on the ground and the hip and trunk come forward, the toe does not come down quickly enough to check the forward movement of the knee and allow the thigh, as it were, " to catch it up."

This, however, is only one of the possible causes of the peculiarity. In some cases it appears to be due to a faulty alignment of the thigh socket upon the knee piece, in which case it may be necessary to fit a new knee piece and set the socket further forward upon it. In some obstinate cases it is thought to be due to idiosyncrasy of the patient—a kind of stammering of the muscles controlling the stump.

Exact rules for alignment, which depend upon measurements based on the contours of segments of the prosthesis, are apt to be illusory, seeing that those parts of the latter which do not enclose the stump may be shaped by the maker arbitrarily for various reasons, æsthetic or otherwise. For instance, some makers shape the thigh socket and shin piece of an above knee leg for a short stump in the form of a scimitar (see fig. 189). It is almost impossible to lay down rules for the position of the knee bolt, based on the anterior or posterior line of the thigh in such a case.

Similarly, the calf may be made large or small, and the position of the middle line of the shin piece affected thereby.

The materials of which artificial legs are made are wood, leather, metal, and compositions such as certalmid, celluloid, or shavings and glue, as made by Dr. Martin at La Panne in Belgium. The wood chosen is almost always willow, which has been found by long experience to fulfil better than other woods the requirements of lightness and strength. It is best when naturally seasoned by long exposure to the atmosphere and to the changes of temperature of the English climate. For this purpose the logs are usually stacked under a shed, which protects them from the direct impact of rain and snow, but allows the air to circulate freely around them.

Fig. 189.

Under the great stress and demand for willow owing to the war, it became impossible to obtain enough naturally seasoned willow, and for much of the material used methods of artificial and comparatively rapid seasoning had to be substituted. This method consists essentially of the application of artificial heat, and has been long known. During the Indian Mutiny, when seasoned wood for the manufacture of carriages and wheels was scarce and transport was urgently needed, Stewart Clarke devised and used a method of baking green wood with complete success.

Although limb makers prefer the naturally seasoned wood, that artificially seasoned has proved useful, and with attention to various details of preparation there is apparently no reason why the process should not be successful.

Willow, like other soft woods, is liable to attacks by insects. Caterpillars, such as that of the willow hawk moth, may make large tunnels in it, and the larva of the sawfly often burrows into it and forms its chrysalis in it. These are generally discovered when the wood is sawn up and roughly shaped, but they have been known to escape notice in a remarkable manner. The thigh socket of a prosthesis now in the Natural History Museum (Entomological Department) was taken from a limb which had been worn by a patient for some time before the first of some dozen sawflies was hatched. The flies (*Xiphydria dromedarius*) were unable to penetrate the hard raw-hide covering of the socket, but made their way out on the inner surface, to the annoyance and dismay of the patient.

Stout leather has been much used for the sockets of artificial limbs, and by some makers and some amputees is preferred to wood; for the pelvic sockets leather has held the field, and is only now being rivalled by such compositions as celluloid and certalmid. Wood is quite unsuitable for these sockets. The leather used is that kind of ox-hide which is known as sole butt or bend.

The advantages claimed for leather are adaptability and freedom from any tendency to split. On account of its flexibility, a leather socket can be made adjustable by means of eyelets and laces, or straps and buckles; but as the lower end of a leather socket must be attached to a rigid wooden part, it is only at and near the top of the socket that any real adjustment can take place. A well-fitting socket is seldom circular, but often roughly triangular in section, but when such a socket is drawn in by tightening the lacing or straps, it at once begins to assume a more circular or cylindrical form, and loses its accuracy of fit. Prostheses with leather sockets are heavier, other things being equal, than those with wood, because not only is a leather socket of sufficient rigidity heavier than a wooden one, but the leather necessitates metal plates to make its junction with the wooden knee or ankle part strong enough.

Wood has the drawback of having a grain, and being therefore liable to split. It is, however, lighter than leather, and as it requires no metal plates to strengthen the junctions between its portions, the resulting prosthesis is still lighter than that with a leather socket. Moreover, a wooden socket can be accurately fitted and adjusted to all the irregularities of a stump. This is specially important in the case of a stump below the knee, which presents several bony prominences which require accommodation.

The practice, introduced from the United States, of covering the wooden parts of leg prostheses with raw hide very much increases the strength of sockets, etc., thus allowing them to be reduced in thickness and rendering them less clumsy.

The hide used is not the whole thickness of the skin, but a thin lamina of it, which, when thoroughly dry and varnished, is only of about $\frac{1}{40}$ inch thick. This is applied after it has been soaked, in which condition it is much swollen and pliable. It is then glued to the socket, temporarily fixed with small tacks, thoroughly dried, its overlapping edges smoothed down and then coated with shellac varnish. In its moist condition the hide can be fitted closely round curves and bosses without wrinkles.

Aluminium and its alloys, such as duralumin, is the only metal which has been used in modern times for the sockets, etc., of leg prostheses. While it is not so adaptable as wood or leather, it has the great advantage of lightness, and this has rendered legs made with it popular to an extent which is perhaps hardly justified by its advantages, seeing that the saving in weight is not very great. A very expensive and very good limb is made of duralumin, and no doubt its lightness accounts to some extent for its popularity; but there are other valuable and important advantages in the limbs made by the particular limb maker in question which have at least as much to do with its popularity and undoubted success.

Celluloid and certalmid, as described in the section on arms, are materials which are also used for the sockets of leg prostheses. They have the advantage of lightness and absence of grain, and their use will probably increase in the future. These materials are always moulded upon plaster casts of the parts in question. As used in the Ministry of Pensions' light legs, they have not the disadvantages of leather.

CHAPTER XV

THE BRITISH OFFICIAL PROSTHESES FOR THE LOWER EXTREMITIES.

THE types of limbs most often used for amputation of the lower extremity are eight in number. Like the arms, these are distinguished in the Ministerial list by numbers, which form a series corresponding to sites of amputations from above downwards.

No. 1. A limb for disarticulation at the hip-joint or amputation so close to the joint as to leave no useful stump for the attachment of an above knee limb.

No. 2. For above knee amputation, leaving a short stump or one which for some reason is not able to control the prosthesis without an artificial hip-joint and pelvic band.

No. 3. For above knee amputations, leaving a stump long enough to give good control of the prosthesis, but not too long for fitting the usual knee bolt and control mechanism.

Nos. 5 and 6. For amputations through the knee-joint or condyles.

No. 7. Kneeling leg. For amputations below the knee in which for any reason the leg stump cannot be utilized.

No. 8. Below knee leg.

No. 11. For leg stumps with knee-joint ankylosed in such a position that No. 7 limb is not applicable.

No. 12. For long stumps for which artificial knee-joints and thigh corset are not necessary.

No. 13. For Syme's amputation.

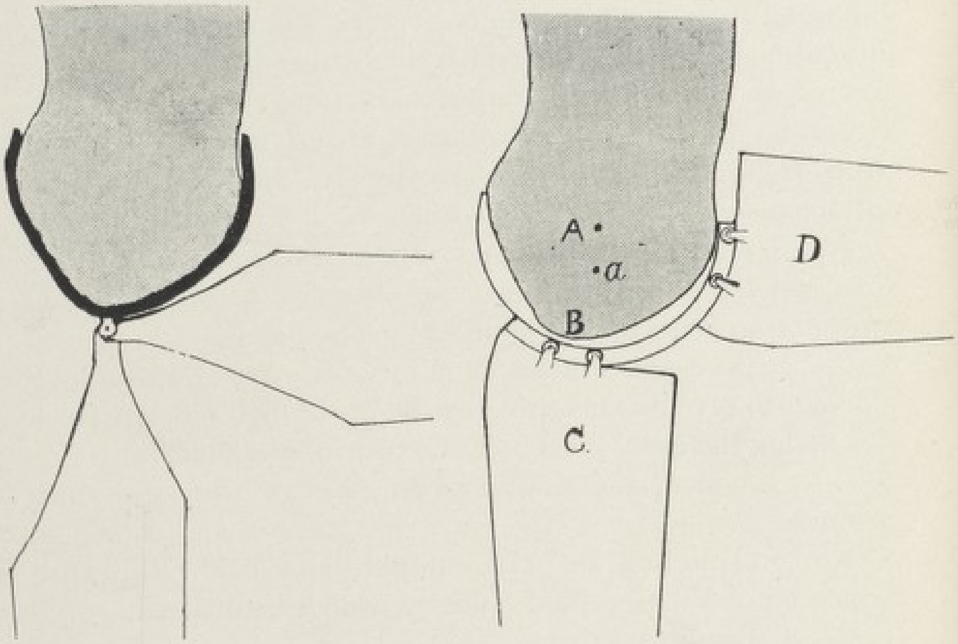
No. 16. For the same when the stump is not end bearing.

No. 18. For Chopart's amputation.

Nos. 4, 9, 14, and 17 represent limbs that are so seldom required that they are only ordered for rare cases, and are then specially prescribed.

The chief difficulty in devising a prosthesis for disarticulation at the hip is caused by the circumstances that while a joint at the hip is a necessity without which the wearer could not sit down, in order to secure sufficient strength and rigidity it is necessary to attach the prosthesis to the stump socket by means of steel joints on the inside as well as the outside, and that it is obviously impossible to place the inner joint anywhere near the inner end of the axis of flexion, because this is situated deep in the pelvis.

If the joint is displaced downwards to meet this difficulty, on sitting the thigh part will be on a plane below the seat of the chair, and will prevent the assumption of a comfortable posture. This is shown in the annexed diagram (fig. 190, *α*).



α *β*

FIG. 190.—(*α*) DIAGRAM OF STANDARD FITTING FOR HIP DISARTICULATION. (*β*) DIAGRAM OF A QUADRANT HIP-JOINT FOR DISARTICULATION.

A, Centre of quadrant; *a*, centre of anatomical hip-joint (acetabulum); B, tuberosity of ischium; C, thigh piece extended; D, thigh piece flexed.

The normal mechanical device for the solution of such a problem is the provision of a quadrant on the inner side of the thigh part to which a corresponding quadrant on the socket is connected, the one working on the other with intervening rollers.

The centre of curvature of the quadrant theoretically should be on the axis of the normal hip-joint. As, however, the centre of the acetabulum in the sitting position is situated not more than 3 inches above the lower border of the ischium, the correct radius for a quadrant would be little more than this. Assuming that the pelvic stump with its covering of soft parts measures, from back to front, 9 inches, the segment of a circle which must contain this stump must have a radius of at least half that amount—that is to say, $4\frac{1}{2}$ inches. If, then, the arrangement is to work, the outer hip-joint must be placed about $1\frac{1}{2}$ inches higher than the joint on the sound limb; but this asymmetry is of

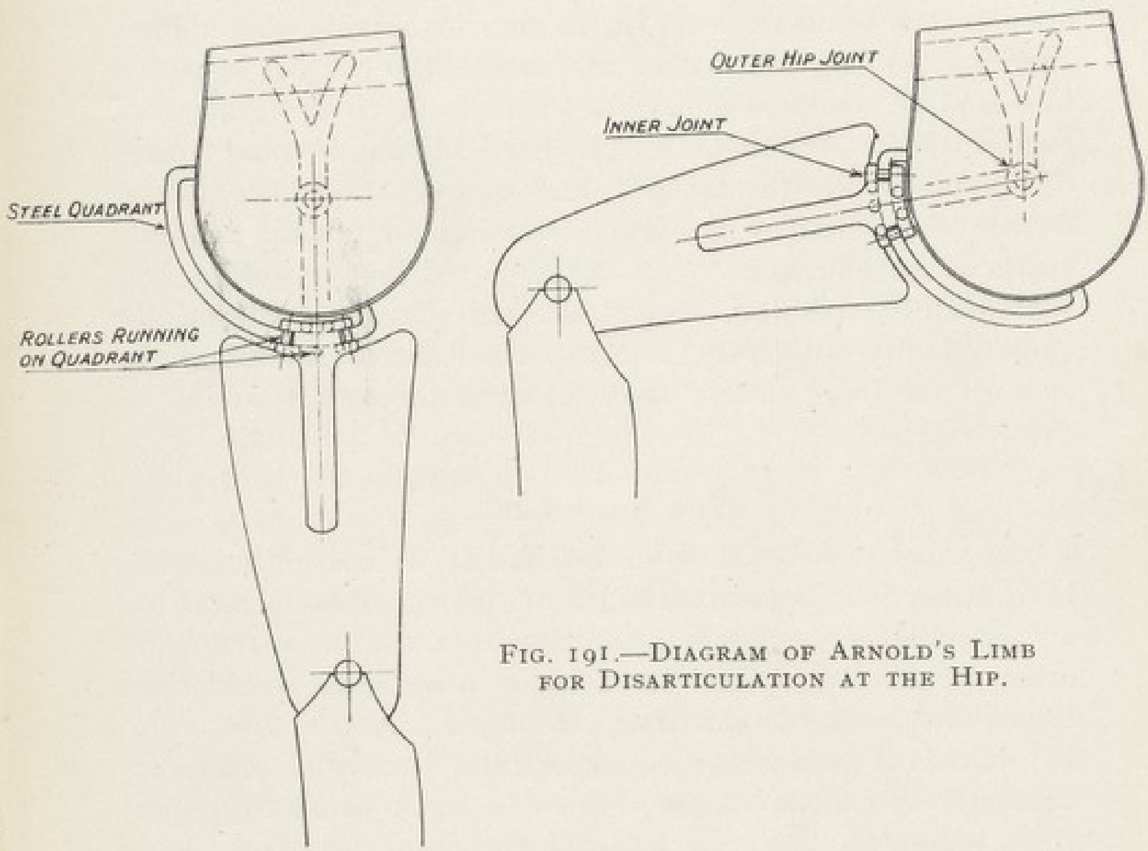


FIG. 191.—DIAGRAM OF ARNOLD'S LIMB FOR DISARTICULATION AT THE HIP.

small importance (see fig. 191). With such an arrangement, in the sitting position the thigh part would assume the natural situation in front of the pelvis, and its posterior surface would rest evenly on the seat of the chair. Such a prosthesis with an ordinary outer hip-joint and quadrant and rollers on the inner side has been made by Messrs. Arnold and Sons, and worn with satisfaction by a patient having the necessary patience and endurance. I am indebted to the superintendent of the Experimental Workshop at Roehampton for the annexed diagrammatic sketch of its mechanism (see fig. 191). Detailed descriptions of limbs constructed on similar principles will be found in G. Schlesinger's article in "Ersatzglieder," etc., 1919, pp. 642-645. The objections to them are, however, great. In the first place, the design is inherently weak, and in order to render it resistant enough the parts have to be somewhat massive, and the whole prosthesis too heavy. Secondly, it is exceedingly difficult to prevent a considerable amount of shake and rattling in use. Thirdly, the quadrant, which is a segment of a circle extending from the bottom of the socket to a point in front of it, and as high up as about 1 inch below the level of the anterior superior iliac spines, cannot be closely adapted to the socket, the contour of which in this place is seldom or never a segment of a circle. Fourthly, even if it were suitable for a true disarticulation, it could hardly be applicable to the fairly numerous cases in which several inches of the shaft of the femur remain and project in front, as these would require a quadrant of too long a radius, and consequently too bulky. In practice, therefore, the anatomically equally faulty prostheses, with the joint centres situated at the level of the inner side of the bottom of the socket, are to be preferred.

The No. 1 Limb.

The usual prosthesis for disarticulation at the hip-joint has been rather inappropriately called a "tilting table." As it has no resemblance to a table, and does not tilt more than any other socket with a joint to it, some other name would have been better. In the classification adopted by the Ministry of Pensions it is known as a No. 1 leg, and it may be most conveniently so called. When the No. 1 leg is fitted to a short thigh stump of, say, 4 or 5 inches of femur, the latter should be flexed and the socket fitted with it in the sitting position, so that weight is taken not only on the ischium, but also on the posterior surface of what remains of the femur (see fig. 192).

The socket of this limb is made most often of leather, but sometimes of celluloid or certalmid, and is supported by thin steel plates, one of which, the tuber plate, passes under the tuberosity of the ischium, to be riveted in front and behind to a steel pelvic band which embraces the upper edge of the socket.

The socket is carried up only far enough to get a good grip of the pelvis, and in no case should extend above the highest part of the crest of the ilium. In front it must be somewhat lower, so as to allow the wearer to lean forward when sitting by means of hyperextension of the lumbar spine. The anterior superior iliac spine should be included in the socket. It is usually moulded upon a plaster cast of the pelvic stump, no matter what material it is made of, although some makers are very successful in fitting leather sockets from measurements and trial.

The steel plate which carries one component of the outer hip-joint is riveted at the top to the pelvic band, as well as to the leather socket below it. This joint is not one used in locomotion, but its sole function is to allow of the patient's sitting down. The height of this joint is determined by the position of the inner hip-joint, which is placed as high up as possible under the lowest part of the tuber plate. In order to ensure that the centre of the inner hip-joint shall be placed as high as possible, this joint is made of as small diameter as is compatible with sufficient strength. It is carried on a bracket, which is riveted securely to the tuber plate.

Theoretically, the two hip-joints might be placed on the same transverse (coronal) line, neither in front of the other, and at the same level, in order to ensure that, when the hip is flexed, as in sitting, the knee and leg should be in a sagittal plane pointing straight forwards at right angles to the general front of the body. In practice it is found that if this is done the prosthesis will appear abducted in the sitting position, which will be unsightly and inconvenient. It is customary, therefore, to bring the outer hip-joint a little forward, thus producing slight rotation inwards, and at the same time to lower it slightly, thus producing slight adduction and bringing the limb well under the pelvis when extended.

The inner hip-joint in the extended position, when the patient is erect, should be situated vertically over the inner ends of the knee and ankle bolts.

When the thigh and knee are rotated inwards in the sitting position, the leg carrying the foot with it will be thrown outwards, so as to give an appearance as of knock-knee. This must be corrected by rotating out the knee piece on the thigh piece so as to compensate for the inward rotation at the hip.

The outer hip-joint is provided with a lock, which locks the joint automatically as soon as the limb is fully extended, being pushed into action by a spring. The wearer unlocks the joint, when he wishes to sit down, by pulling on a knob or sleeve. This can be done through the clothing, or conveniently by the hand in the trouser pocket.

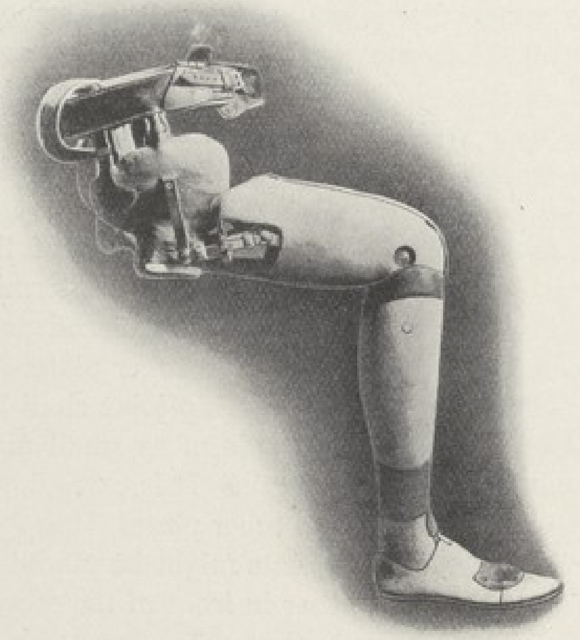


FIG. 192.—"TILTING TABLE" LIMB BY F. G. ERNST, LONDON.

The action of the leg is as follows: In the upright or standing position the patient has the outer joint locked by means of the ring catch, and walks with the leg perfectly rigid at the hip; but when desirous of sitting, the trigger is raised and the joint is made free; this joint now acts as a hip-joint, enabling the patient to sit down, as shown in fig. 193, the tilting table still being in position on the stump. When the patient desires to rise, the hip-joint locks automatically (fig. 194). The limb is attached to the body by "Ernst's" pelvic band.

There are two types of hip lock, the ring catch and the bolt and slot. The ring-catch joint is well known among orthopædic surgeons, who use it frequently to lock the knee-joints of instruments for paralysis of the quadriceps. In this lock the male part, which is below, is prolonged upwards between the jaws of the female part, so that on flexion of the joint it protrudes between them, but is flush with them in the extended position. Locking is effected by a steel sleeve or ring which slides down over the two parts and prevents movement. By adding a spring which pushes down the ring, the joint is made to lock itself as soon as it is fully extended.

In the bolt-and-slot type of lock the female component of the joint is situated below, and its outer jaw is prolonged upwards. This jaw has a slot cut in it parallel to the axis of the

FIG. 193.

steel plate and of the limb, into which a bolt is pushed by a spring when extension is complete.

There can be little doubt that the ring-catch lock is the better and stronger one of the two, and one of this type has been standardized by the Ministry of Pensions.

The lower component of each hip-joint—the male part when a ring-catch lock is used—is fixed by means of copper rivets to a wooden thigh piece, which serves to fill out the clothing and at the same time fulfil the more important rôle of connection and support between the pelvic socket and the knee piece and leg below. The upper part of this thigh piece has to be cut away in front in order to allow of flexion at the hip when the wearer sits, and it has also to be cut away behind in order to

FIG. 194.

make room for the seat of the chair, for the reasons already stated. This cutting away of the thigh piece much weakens it, so that occasionally the wood splits and the hip-joint breaks away from it. In those limbs which are made with a metal framework continuous with the knee-joint this source of weakness is avoided, and the thigh piece becomes purely ornamental, as will be seen when metal limbs are described later.

The wooden thigh piece already described is almost cylindrical, but slightly tapered at its lower end, which joins the top of the knee piece, to which it is fixed by glue and four or more hard wood keys, the joint being further strengthened by the raw hide covering the whole segment.

This is the usual practice, and the most convenient, but the thigh and knee may be made in one piece. The knee piece of the standard limb has been already described, together with the central knee control. Its curvature is the segment of a circle of which the centre is the centre of the knee bolt, so that the top of the front of the shin piece, which is carried as close as practicable without touching, shall preserve that relation in all stages of flexion. The back of the shin piece is cut away enough to allow full flexion of the knee; this must be so much as to allow the patient to kneel comfortably with the point of the toe resting on the ground, which corresponds usually to an angle of 75 degrees between the longitudinal axes of the thigh and shin segments.

The knee piece is connected with the shin piece by means of two side steels, which are riveted to the wood of the latter and project above it so as to lie one on each side of the knee piece. The knee bolt passes through circular threaded openings in the side steels and through the wood of the knee piece, from which it is separated by a leather lining technically called a bush. The knee bolt, which is slightly tapered, is screwed into the side steels and secured with a locking screw. Thus the knee bolt turns with movements of the shin piece, and friction takes place between it and the leather bush. Moving with the knee bolt are the rollers of the central knee control, which are either attached directly to it, as in the Hanger limb, or to the knee lever, which moves with the shin piece and knee bolt, as in the Rowley pattern, which has been adopted for the standard limbs.

The shin piece, which is shaped to resemble the natural calf, may be made all in one piece with a solid lower end, or it may be in two pieces with a keyed and glued joint. In either case the solid lower end is slightly expanded to represent the shape of the ankle, and to its lower surface is glued the hard wood ankle block, which is generally made of beech wood. This is expanded laterally to the width of the natural ankle, forwards to represent the beginning of the instep, and backwards that of the heel, or rather of the tendo Achillis. It is further secured by two steel wood screws. The under-surfaces of the front and back expansions bear upon the rubber heel and instep buffers. Through the ankle base and the solid end of the shin piece two bolts pass upwards which carry the ankle bolt and its grooved bronze bush. These bolts are secured inside the bottom of the shin piece with washers and nuts, and they, as well as the wood screws, hold the ankle base firmly in position. The ankle bolt is thus one with the shin and ankle piece, and movement takes place below it in the joint between it and the top of the foot, which is shaped to receive it and the bronze bush. This part of the top of the foot is covered, where exposed to friction, with a raw hide bushing. The functions of the bronze busn are: (1) To take the friction of the steel staple; and (2) by being partially imbedded in the hide bushing below, to prevent lateral play. The ankle staple of steel passes over the bronze bush, in the groove of which it rests; its two limbs, which are screw-threaded, pass through two holes in the foot and in a steel plate on the sole, to be secured by two steel nuts and a locker plate. These and other details will be more clearly understood by reference to the specifications and drawings of the standard limbs of the Ministry of Pensions.

The toe-joint should be placed at the junction of the anterior third with the posterior two-thirds of the foot, with its axis at right angles to the longitudinal axis of the foot. In the older types of leg the toe piece was hinged to the rest of the foot by means of a brass hinge fixed to its lower (plantar) surface. The upper part of the contiguous surface of the toe and of the foot were cut away, so that when the toe was fully extended there was a gap, V-shaped in longitudinal section, between the upper surfaces of the two parts.

In this gap a spiral steel spring or springs was inserted, which, being compressed by dorsiflexion of the toe-joint, expanded and extended the toe as soon as pressure was removed. With the substitution of a hinge of balata or leather for brass and of indiarubber for spiral steel springs, the above description applies to the toe-joints now generally used. The toe-joint is covered in above with thin leather, as described in the specification in the Appendix.

A toe-joint without spring, but with a lever which extended the toe on pressure of the sole on the ground, at one time was used, but may now be considered obsolete, and need not further be described.

Rubber feet have been used for many years, and if made of good material they are very durable and at the same time resilient. The well-known leg of Marks of New York has been made for years with a rubber foot and no ankle- or toe-joint, the pliability of the rubber acting instead of the joint. This foot has not, however, been popular in this country. Solid rubber feet have the drawback of weight, but the sponge rubber foot lately introduced by Messrs. Rowley is as light as a wooden foot and very resilient. Its construction is shown in the annexed figure, where 1 is the sponge rubber, 2 and 3 are the instep and heel buffers of rubber, and 4 points to the ball bearing

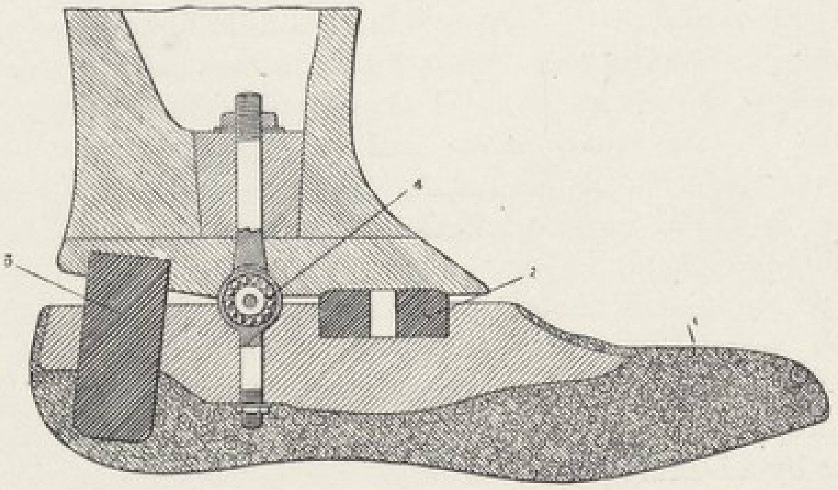


FIG. 195.—SPONGE RUBBER FOOT BY J. F. ROWLEY AND CO., LTD.
1, Sponge rubber; 2, instep rubber buffer; 3, heel rubber buffer; 4, ball-bearing ankle-joint.

ankle-joint. The lightly shaded part of the figure represents the wooden shin piece, ankle base, and foot core.

Artificial feet should always be made to fit the fellow of the boot worn on the sound foot. If the foot were made an exact counterpart of the sound foot, it would be found impossible to get the boot or shoe on to it, because of its unyielding nature. It therefore has to be made narrower and slightly smaller, but not so small as to be loose in the boot.

The No. 2 Limb.

The No. 2 limb for short thigh stump and the No. 3 for longer thigh stumps differ only in the circumstance that the former is fitted with an artificial hip-joint and pelvic band.

Pelvic bands and artificial hip-joints have been used for many years by orthopædic surgeons in the walking instruments of cases of flaccid paralysis. Some kind of pelvic band and hip-joint has been used from time to time for artificial limbs (see A. Hoffa, "Lehrbuch d. Orthopädischen Chirurgie," Stuttgart, 1891), but the pelvic band and hip-joint, as used for instruments for paralysis, was adapted to artificial limbs by F. G. Ernst some years ago, and came into general use in this country for short thigh stumps in 1915 (see fig. 183 on p. 180).

The uses of a pelvic band and hip-joint are to limit the movements of the prosthesis, when from shortness of the stump or weakness of muscles or other complication it cannot be controlled by the stump alone, and to prevent a short stump from slipping out of the socket. The hip-joint generally fitted allows the full range of flexion, but strictly limits ab- and adduction.

The hip-joint is of steel, and consists of an upper (male) and lower (female) part connected together by a steel screw bolt. The male part, which bears the friction of the bolt, is lined with a phosphor-bronze bush. The bolt is prevented from working loose by a locking plate or a grub screw. The male part, which is T-shaped above, is riveted to the steel of the pelvic band. The band extends from a point in front of one anterior superior iliac spine to a point in front of the other, and should be placed at such a level that it is not so low as to impinge on the top of the socket when the thigh is fully flexed, but yet so placed as to lie below the crest of each ilium. The centre of the hip-joint being placed so as to correspond to the level of the tip of the great trochanter, if the male part is too long the band will lie too high; if it is too short, it will touch the socket on flexion.

The pelvic band is made of shear steel $1\frac{1}{8}$ inches wide and of No. 16 to No. 18 imperial wire gauge in thickness, and it should be fitted carefully and accurately to its place on the pelvis before it is tempered and before the male part is riveted to it. After tempering, it should be placed again in its proper position as nearly horizontal as possible as viewed from the side. The position of the male part upon it should then be marked out, after the position of the female part upon the socket has been determined. This position should make the male part (the patient being erect) nearly vertical, although this condition may make it necessary to fix the T-piece in a line not parallel to the pelvic band. If great care is not taken in settling these details, the band will be uncomfortable and unsatisfactory in many cases.

A considerable strain is put upon the steel band by men who are very active or follow laborious occupations, so that breakage is not uncommon. This may often be obviated by shortening the steel so that it does not extend quite so far as the middle of the back, forming what is called a "short steel pelvic band." Often this will be found to give sufficient support, while allowing enough play to avoid breakage.

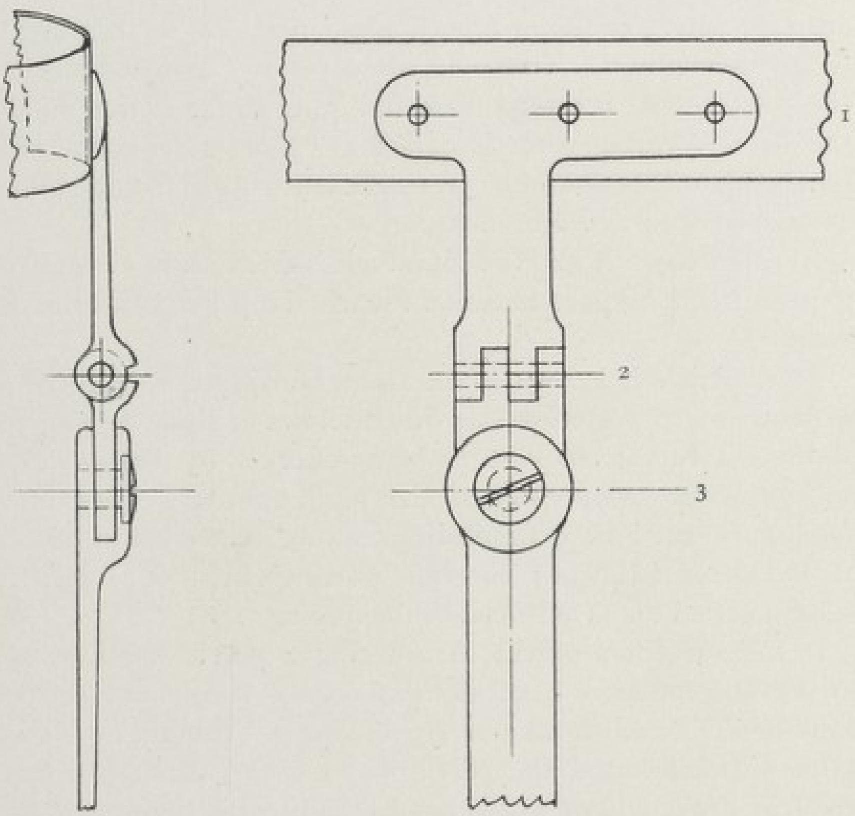
In other cases it may be found advisable to add an additional joint in the male part between the usual hip-joint and the pelvic band.

This, which is known as an abduction joint, is a hinge-joint with an antero-posterior axis which allows of some 15 degrees of abduction, further movement being checked by a stop shoulder on the lower component of the joint. Such a joint is very commonly used in orthopædic walking instruments for cases of paralysis following anterior poliomyelitis, etc., but it is seldom called for in artificial limbs (see fig. 196).

If the surgeon's object in ordering a pelvic band be solely to prevent the limb from slipping off the stump, a steel pelvic band is unnecessary, for this object can be attained by a leather band buckled round the pelvis and passing through a leather loop the lower end of which is attached to the outer part of the top of the socket. The elaborate Desoutter pelvic band, which serves the same purpose, will be described later in considering aluminium limbs.

Every steel pelvic band is padded on the inside and covered inside and out with leather, which is continued beyond the steel and furnished with a strap and buckle.

The thigh socket, whether it be of wood or leather, should accurately fit the stump all round; it should offer a good seat for the tuberosity of the ischium, but should not press on the ascending ramus of that bone or on the pubis. In the absence of end bearing (and few short thigh stumps can bear much weight on their ends), the pressure of the socket is taken by the tuber ischii, by the outer side of the stump below the great trochanter, and by the soft parts of the buttock. The outer side of the socket should come up nearly as high as the top of the great trochanter, and should not be more than 1 inch below it in any case of short stump. When thus made, the highest point of the outer side of the socket may be as much as 4 inches higher than the lowest point of the inner side. In the front the slope



Antero-Posterior View. Lateral View.

FIG. 195.—ABDUCTION JOINT. (From a drawing by Mr. N. B. Jones.) 1, Pelvic band; 2, abduction joint; 3, ordinary hip-joint.

between these two points may be nearly continuous, although it may be necessary to scoop out somewhat the part near the groin. In the posterior half of the bucket, if the slope is made continuous so that the tuberosity rests upon an inclined plane, there will be a tendency for this bone to slide forwards and downwards when weight is put upon it.

If it does so slide, the whole stump must rotate outwards relatively to the socket, the evident effect of which will be a rotation of the socket inwards when weight is borne upon the prosthesis. Besides this unsightly and disabling rotation, there will be discomfort and a sensation of insecurity, and the consequent friction at every step between stump and socket will cause soreness and excoriation. The change of level, therefore, should be interrupted; it should be in steps, as it were, instead of continuous, and the tuber should rest upon a nearly horizontal bed, in front of which the edge of the socket should drop to clear the ramus of the pubis and the tendon of origin of the adductor longus.

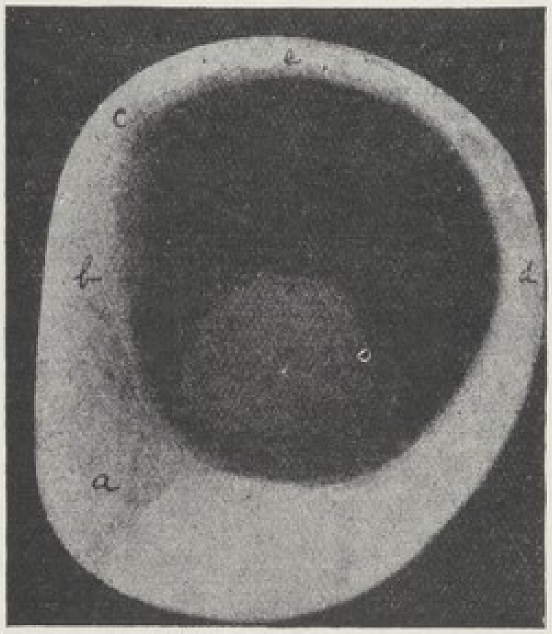


FIG. 197.
Showing the roll on the inner side of the socket and the broad shelf under the ischium. This socket is unusually round in section.

There should be a *roll*, as it is called, or lip to the inner and posterior part of the socket, so as to provide a shelf instead of an edge on which the tuberosity rests, and to prevent pinching of the skin of the buttock. This lip must not be wide in that part of the inner edge which is situated in front of the ischium, or it will be likely to rub against the opposite thigh (see fig. 197).

In horizontal section a thigh socket should be roughly triangular, or, more properly speaking, circular with three flattened segments—namely, the inner, anterior, and external—the angles of the truncated triangle being situated respectively at the ischium, the tendon of the adductor longus, and the great trochanter (see fig. 198).

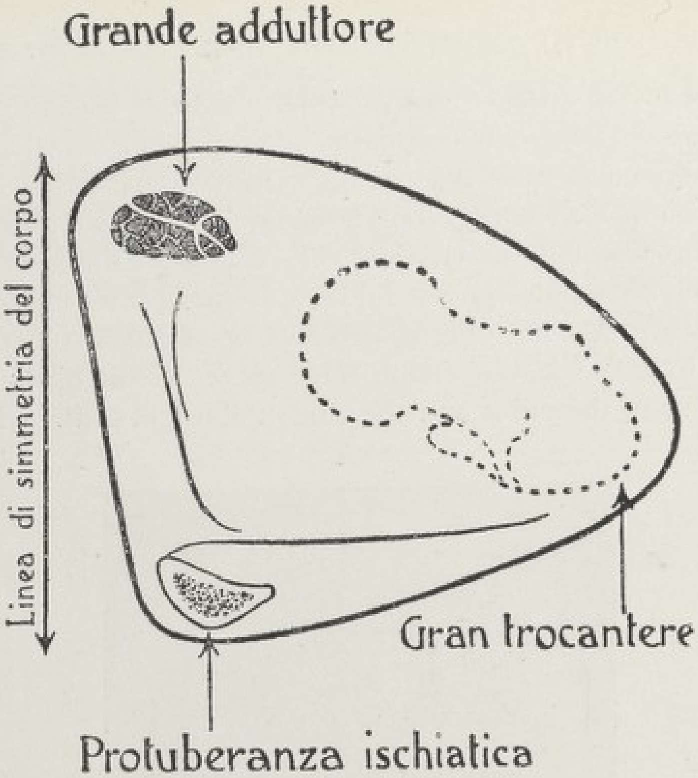


FIG. 198.

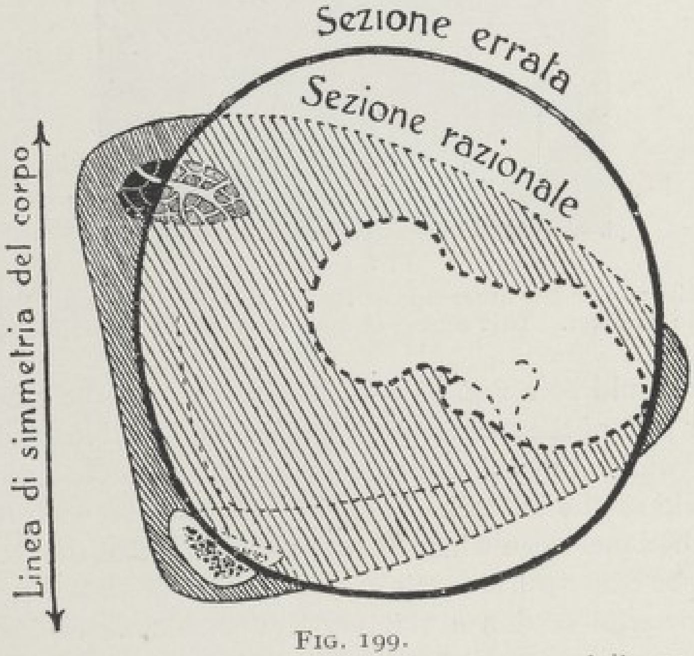


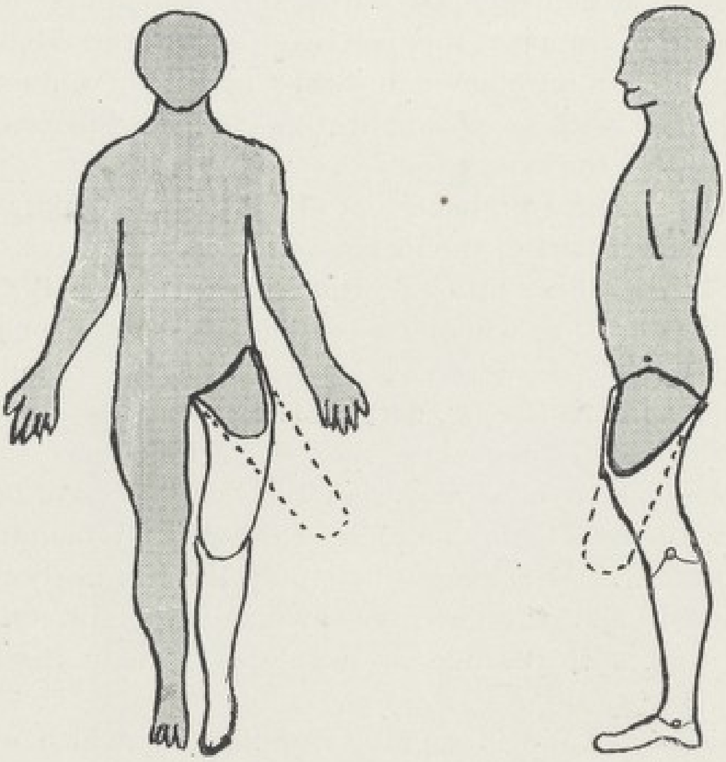
FIG. 199.

These two figures (by V. Putti, *Medical Supplement*, vol. ii., no. 1, p. 15) show with some exaggeration the form of a horizontal section through the upper part of a thigh stump. The head, neck, and great trochanter of the femur are outlined, but it is obvious that they would be above such a section, which passes through the tip of the tuber ischii.

Translation: *Grande adduttore* = Adductor longus; *Linea di simmetria, del corpo* = median line of the body; *Protuberanza ischiatica* = tuber ischii; *Sezione errata* = wrong section; *Sezione razionale* = correct section.

The patient's first socket will probably be nearly circular in section, except for a flattened inner side; but as those muscles atrophy, the section will be found to be more triangular.

As the socket has to be joined to the nearly cylindrical knee piece, its triangular form is modified below the end of the short stump, and becomes more and more round as it is carried down till it corresponds in section to the top of the knee piece.



A B

FIG. 200.—DIAGRAM OF CONTRACTED THIGH STUMP.

The broken outline shows the position that would be taken by the thigh if a straight socket were to be fitted. The unbroken line shows how the knee and leg are brought back into the position necessary for support by curving the socket below the stump. Such limbs are best made shorter than the normal, especially in cases of abduction deformity.

A, Accommodation of abduction; B, accommodation of flexion.

The thigh socket is joined to the knee piece with glue and hardwood keys, just as has been described in the case of the thigh piece of the No. 1 limb. From this level downwards, the description already given of the limb for hip disarticulation applies also to those for short and long thigh stumps after amputations 3 inches or more above the knee-joint.

When there is loss of normal range of movement at the hip, and permanent contraction preventing full flexion or reducing the range of movement of adduction or abduction, it becomes most important to accommodate the deformity. In a bad case of flexion contraction, if the deformity is not properly accommodated in the socket, the patient will be unable to assume the upright position with the knee straight, but will be bent forwards at the hip. In a case of abduction contraction, similarly, the prosthesis would be directed outwards, and could not be brought into position to support the pelvis. Flexion and abduction contraction are not uncommon in short stumps, but adduction is very rarely met with as a complication. These difficulties are met by adjusting the axis of the socket to the deformity, thereby throwing the end of it probably out of the line of support of the body. The lower part of the socket and knee piece have, therefore, to be brought back into a position to secure stability. This may be done partly or wholly by curving the socket, or partly by joining it to the knee piece at an angle which is rounded off in finishing the limb (see fig. 200). The longer the stump the less easy it is to accommodate the contraction, since the distance of the end of the stump from the line of weight-bearing increases with the length, the angle of deformity remaining the same. Fortunately, the longer the stump the less likely is it to be contracted, and the leverage available for correction of deformity makes it possible, as a rule, to remedy it when it occurs.

Ankylosis of the hip is a grave complication which will be dealt with later.

The No. 3 Limb.

The No. 3 limb for long thigh stumps differs from the No. 2 only in that it has no artificial hip-joint and no pelvic band. It is not necessary in the case of a long stump to carry the outer side or front of the socket so high up as in a No. 2, but in all limbs for above knee amputations the socket must reach at its inner posterior part to the tuberosity of the ischium.

An objection to carrying the front of the socket high up is found in the tendency of such a socket to slide downwards upon the stump when the patient sits. This displacement is caused by the changed relations of the soft parts with the socket when the hip is flexed. If the top of the socket comes in contact with the groin in an early stage of flexion, further flexion is only possible if the socket slides downwards on the stump. In some cases, no doubt, the back of the top of the socket tends to slip off the chair, and so aggravate the trouble. The partial withdrawal of the stump from the socket disturbs the relations between them, so that on rising to the erect position the stump may sometimes fail to find its proper place. This sliding down makes the knee of the artificial limb project beyond the natural one, which makes an unsightly appearance, and also causes the leg to be in the way in public conveyances, etc. Despite pelvic

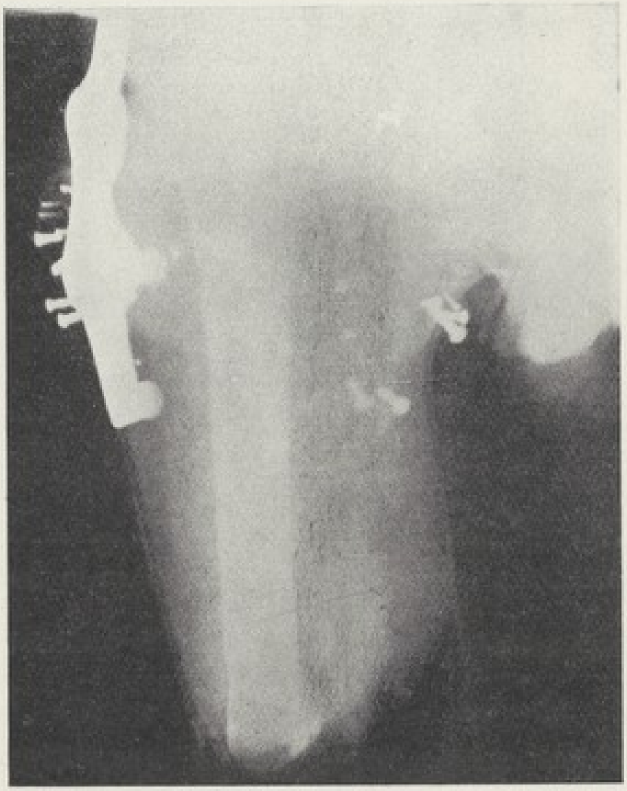


FIG. 201.—X-RAY PICTURE OF A LONG THIGH STUMP IN THE SOCKET OF A NO. 2 PROSTHESIS.

The wooden socket casts a scarcely perceptible shadow, but the metal parts are very obvious.

bands of different sorts, this movement cannot always be obviated. If to conceal it the segment above the knee is made shorter than the natural, the below knee segment must be lengthened, thus raising the artificial knee above the natural. Some patients, however, prefer a raised knee, which is only unsightly in appearance, to an anterior projection, which is inconvenient as well as unsightly.

The annexed figures show the usual position of long and short thigh stumps respectively in the socket when the limb is worn. For these radiographs I am indebted to the kindness of my friend and colleague, Dr. Stanley Melville. It will be seen that the femur lies entirely on the outer side of the stump, and

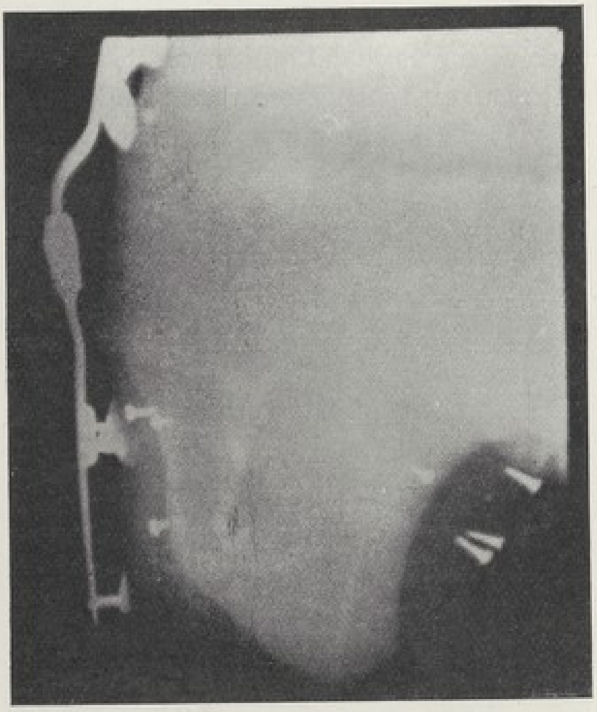


FIG. 202.—X-RAY PICTURE OF A SHORT THIGH STUMP UNDER SIMILAR CONDITIONS TO THE PRECEDING.

Both patients were putting weight on their artificial limbs.

that pressure is taken on the femur on that side and on the ischium on the inner side, very little resistance being offered by the soft parts on the inner side of the thigh.

Through Knee-Joint or No. 6 Prosthesis.

When the site of amputation is through the knee-joint or through the condyles, two complications are introduced. Firstly, owing to the bulbous state of the stump, it cannot be accurately fitted into a rigid socket, because the expanded end of the stump would not pass through the narrower part just above the end of the socket. It is necessary to make that part narrow in order that a good grip of the stump should be obtained.

Secondly, owing to the length of the stump, a transverse knee bolt cannot be used, as in the No. 2 and No. 3 limbs, because the stump itself intervenes between the sides of the socket, where the knee bolt would be situated.

The first difficulty is overcome by making the socket entirely of leather, which has an opening in front extending from the top nearly down to the lower end. This allows the expanded end of the stump to be pushed down into place, after which the sides of the socket are drawn together by lacing or by straps and buckles.

To overcome the second difficulty a knee-joint has to be provided on each side of the socket, formed by two steel plates, one of which is affixed to the exterior of the leather socket and the other to the exterior of the wooden shin piece.

The annexed illustration shows the construction. Extension of the knee is helped by an elastic and by so-called crutch straps attached to the shin piece below and to the suspenders or to a waistbelt above, as described at greater length in the section on the No. 8 leg. The amount of hyperextension allowed is regulated by a leather thong laced through eyelets in tabs attached to the back of the socket and of the shin piece respectively, forming what is known as a "check lacing." The suspenders or waistbelt, as the case may be, are connected behind with the socket by means of an elastic "back lift."

FIG. 203.—No. 6 HANGER.

For heavy patients it is sometimes advisable to join together the lower ends of the two steels on the thigh by means of a curved steel which passes round the lower end of the socket. This counteracts any tendency to spreading of the lower end of the socket and the knee-joints.

If the stump is fit for end-bearing a sponge rubber pad, ½ inch thick, covered with leather, is placed in the bottom of the socket, and on this the end of the stump rests. It is seldom that it will be possible to bear all the weight on the end. A considerable proportion will be borne on the circumference of the stump by firm lacing of the socket and by the tuberosity of the ischium, up to which the top of the socket should in nearly all cases extend.

A No. 5 leg is sometimes ordered for amputations through the knee-joint. This has a wooden socket of which the front is cut away in its lower part and closed in with a lacing piece of leather. In other respects this limb resembles the No. 6. The No. 6 limb is in most cases preferable.

The No. 7 Leg.

The No. 7, or kneeling leg, is intended for leg stumps which are too short to be usefully fitted with a below-knee limb—that is to say, as a rule, for stumps less than 3 inches in length below the joint, although in a few cases stumps of 2 inches only have been successfully fitted with No. 8 limbs.

The No. 7 limb is also suitable for short below-knee stumps of which the knee-joint is ankylosed at or near a right angle.

It is of the same type as the No. 6 limb, but differs from it in the shape of the lower end of the socket, which is expanded backwards to include the stump of the lower leg. This may be entirely closed in behind, or the projection may be minimized by leaving all but the periphery of the end surface of the stump uncovered.

These stumps are generally end bearing, and a sponge rubber pad is fitted, as in the No. 6 limb. Some weight, however, must be taken by the circumference of the stump and by the ischium, for it must be remembered that the patella and the anterior surface of the knee and top of the tibia are not naturally weight-bearing surfaces, despite the time-honoured practices of religious devotees and charwomen. The familiar disease of housemaid's knee is evidence to the contrary. Naked and primitive man, to whose practices, since the days of J. J. Rousseau, it is fashionable to turn for teleological authority, does not habitually kneel when he wishes to perform any task near the ground. He squats on his haunches. To go back to still more primitive examples, the higher apes are, I believe, not known to kneel.

The No. 8 Leg.

The typical below knee limb—No. 8—is suitable for all stumps from 3 inches long down to a level 3 inches above the ankle. At the time when H. H. Bigg wrote his book on artificial limbs (in 1855) it appears that for below knee stumps no knee-joints were used. Long stumps relied upon the socket alone, which was prevented from dropping off by straps attached to a leather band above the condyles of the femur. Short stumps were fitted with kneeling limbs, doubtless because it was impossible to enable their possessors to walk without steel knee-joints and thigh corsets, which, however, had come into vogue before Bigg's book, "Orthopraxy," appeared in 1877.

Only a very few of the below knee amputees of the last war are able to dispense with the knee-joint and thigh corset.

There are two methods of fitting a below knee leg. That which was usual in this country up to a few years ago relied more upon a stiff thigh corset carried high up than on accurate fitting of the socket below the knee. In some limbs of this kind all the weight was carried on the thigh and ischium, and the stump merely served as a lever with which to flex and extend the prosthesis below the knee.

In many cases what is called a slip socket was used. This consists of a leather case, preferably moulded upon a plaster cast, partially split at the back, and adjustable by means of eyelets and lace. This slip socket fits as closely as possible to the stump, and is kept pulled well up on it by two elastic straps attached to the thigh corset above. On the front edge of the socket is a leather shelf, which rests on the top of the wooden socket when the foot is pressed upon the ground. The wooden socket has to be made proportionately large to accommodate the stump plus the slip socket (see figs. 204 and 205).

It is intended that, instead of up-and-down friction occurring between the stump and the socket, the two shall remain in close contact, and any unavoidable pumping motion should take place between the slip socket and the wooden one.

What may be called the American method of fitting below knee limbs was introduced into this country when it became necessary, owing to the number of amputees, to supplement the efforts of the British limb makers with extraneous aid. This method aims at making the greatest possible use of the stump by fitting the socket as closely and accurately and as high up as possible, and using the thigh corset as a secondary and not a primary means of support. In this way, shorter stumps can be successfully fitted than can be done by the first-mentioned method, and the thigh muscles are compressed as little as possible, so as to allow them to act and to avoid atrophy.

The comfort of the patient depends largely on the skill of the fitter of the wooden socket.

If it is well made pressure will be evenly distributed over the sides and front of the stump, without undue incidence on any one spot. To achieve this, adequate hollows must be scooped out for the head of the fibula and the tubercle and inner tuberosity of the tibia. The top of the socket impinges upon the ligamentum patellæ just below the lower border of the knee-cap, and is slightly hollowed out so as to accommodate it. The back of the socket is flattened and carried up as high as is consistent with convenient flexion of the knee.

No. 8 limbs are generally worn over two woollen stump socks.

FIG. 204.—SLIP SOCKET BY W. R. GROSSMITH, LONDON.

FIG. 205.—SLIP SOCKET IN SITU IN LEG BY W. R. GROSSMITH, LONDON.

The annexed figure represents such a socket and shows its roughly triangular cross-section (see fig. 206).

However well and closely sockets are fitted, there are cases in which it will be necessary to combine with the high-fitting socket a blocked leather thigh corset bearing upon the tuber ischii, and it may even be necessary to support the leather under the tuberosity by a metal plate attached to the inner side steel.

For very difficult and sensitive stumps, these methods may have to be combined with the slip socket, but the proportion of cases for which the slip socket has been found necessary at Roehampton is small. It makes rather a clumsy leg, and is objected to on that account.

Some surgeons hold that thigh corsets should always be stiff and take a tuber bearing. The writer's experience and that of many others leads him to hold that this is an extreme view. If the limb fitter knows his business and is reasonably skilful, the

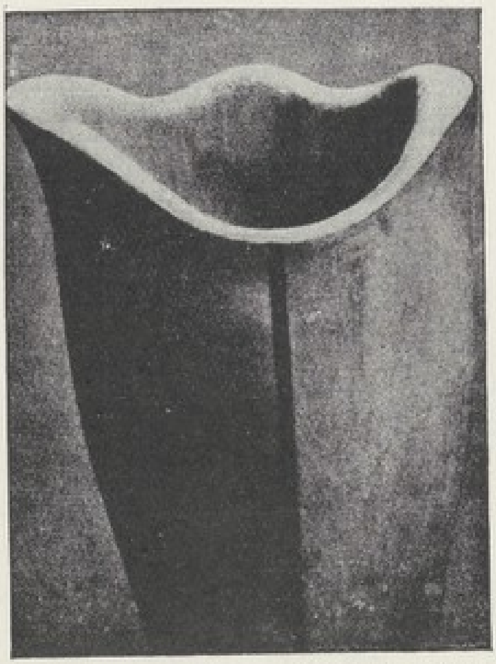


FIG. 206.—WOODEN SOCKET OF BELOW KNEE LEG.

tuber bearing is generally unnecessary. Moreover, it is by no means an unmixed blessing to the wearer. The pressure on the tuber is often irksome, it restricts freedom of movement, and it often causes unpleasant jars, as, for instance, when the amputee jumps down on to the artificial foot; it also increases the total weight of the limb. For these reasons many men dislike the high-fitting stiff thigh corset. It is usually made to open in front throughout its length and to lace up, but in some difficult cases it may be preferable to substitute for this an undivided short thigh socket of blocked leather, accurately fitted as if for an amputation in the upper part of the thigh. As this does not extend below the middle of the thigh, it is large enough to allow the stump and knee-joint to be passed through it. The lower part of the thigh below this socket is supported by a padded strap or a lacing piece across the front of the limb.

Some makers modify this thigh socket by making only the upper 2 or 3 inches a rigid cylinder, and adjusting the rest by an opening and eyelets or lace.

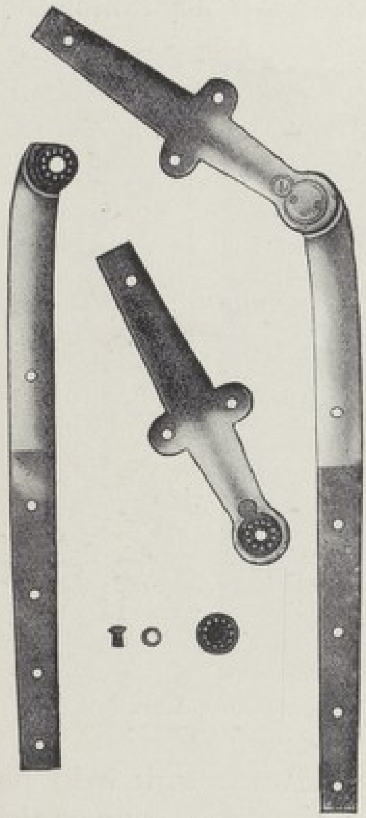


Fig. 207.—Ball Bearing Knee-joint (Rowley).

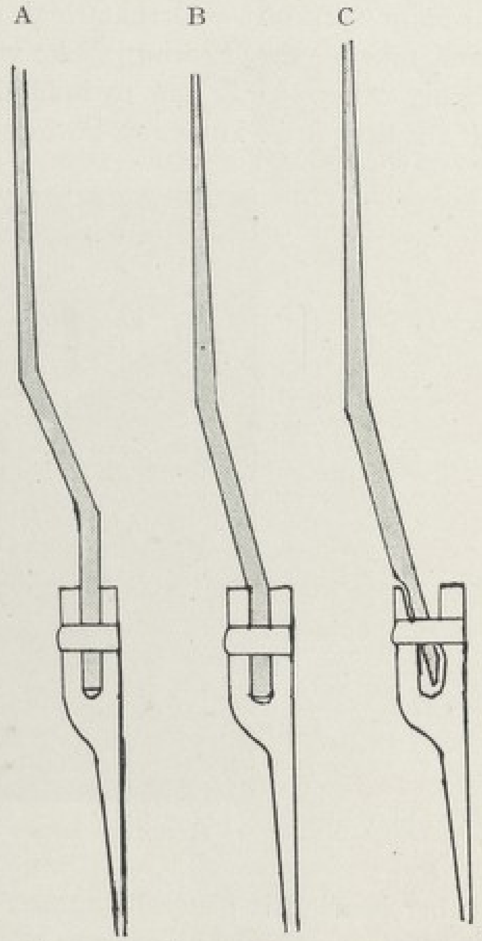


Fig. 208.—Shows Wear owing to Faulty Cranking of Steels.

A, Properly cranked; B, improperly cranked; C, result in wear after improper cranking.

What has already been written about joints in general applies to the side steels and knee-joints of No. 8 limbs. It is for these joints chiefly that some makers have vaunted the merits of ball bearings. The annexed illustration shows a good type of this knee-joint, made by Messrs. J. F. Rowley, Ltd. If bushed mortice-and-tenon joints are properly fitted, ball bearings are unnecessary.

Unfortunately, on adapting the upper side steels to individual cases careless fitters may do mischief. When the steels are properly cranked, as in A, fig. 208, the parallelism of the upper and lower components of the joint is preserved, and on movement there is no unequal strain on either side of the joint. If, however, as in B, the upper steel has not been properly held in the vice or wrench when it was cranked, a cross strain will occur, and the joint will work stiffly and its surfaces will be worn away quickly in use, as shown in C. Such wear is too often seen when pensioners return for repairs after careless fitting. The result is an insecure and rattling joint. It is important also that the axes of the two joints should be in the same straight line, and that their planes of movement should be exactly parallel.

Faults in any of the above conditions of the knee-joints should be detected, when the limb is first supplied, by careful examination, which will show that the badly adjusted joint does not work freely.

No matter how long the below knee stump is, it is generally advisable to give it some assistance in extending the leg. In the case of a short stump it is imperative to do so. This is done by means of an extension strap, forked below where it is attached to each side of the shin, and connected above with suspenders which pass over the shoulders. A strong piece of elastic webbing is interposed between the forked strap and the suspenders. This is called an elastic crutch strap. The advantages of the forked strap are that on flexion of the knee, as in sitting, the branches of the fork fall one on each side of the knee, and do not form a prominence on the top of the knee under the trousers. Wear and tear is thus reduced, and also, in this position, the elastic is relaxed, and any tendency to unwanted extension of the knee is obviated (see fig. 209).

FIG. 209.—No. 8 HANGER.

Some amputees learn to walk well with No. 8 limbs without shoulder suspenders, which are often irksome. A broad webbing belt stiffened with vertical cross strips of duralumin is fitted

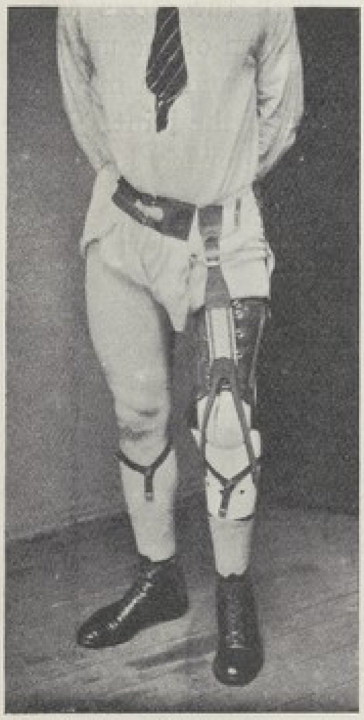


Fig. 210.

Fig. 211.

FIG. 210.—BELT FOR SUSPENSION OF NO. 8 LIMB, MADE BY J. F. ROWLEY, LTD.

FIG. 211.—SUSPENSION OF A NO. 8 LEG FROM A BELT INSTEAD OF FROM SHOULDERS, SHOWING THE PATIENT'S POWER OF LIFTING AND EXTENDING THE LEG.

This patient's stump is only 3 inches in length. As suggested by the wearer, Sergeant-Major Whitton.

round the upper part of the pelvis, and to this the elastic crutch strap is attached. Wearers of this belt find the relief from shoulder strain a great advantage (see figs. 210 and 211),

The No. 11 Leg.

When the site of amputation is below the knee, but the knee-joint is ankylosed at such an angle that a kneeling leg, such as No. 7, is unsuitable, a prosthesis similar to the latter is prescribed, but very little weight can be taken on the below knee stump, and therefore the sides of the thigh and the tuber ischii have to take most of it.

If the stump of tibia and fibula is ankylosed at an angle of

135 degrees and is longer than 6 inches, there will scarcely be room for it in an ordinary trouser leg. The more acute the angle, the less the length that can be accommodated. Such a leg is awkward and unsightly, and necessarily somewhat heavy. The longer the below knee stump, the more does it get in the way.

This type is seldom wanted. Patients with such stumps are generally willing to submit to reamputation above the condyles, which affords a good weight-bearing stump, which can be fitted with a No. 3 prosthesis.

The No. 12 Leg.

This is a leg for a long below knee stump on which the patient is able to bear the whole of his weight without the help of a thigh corset and steels and knee-joints. A lacing piece a few inches deep is fitted above the condyles of the femur, to which the socket is attached by two side straps. This arrangement is designed simply to prevent the prosthesis from falling off when the foot is off the ground.

The cases suitable for this type are few and far between, and it can never be safely ordered until after the patient has well tested his capabilities with a No. 8 leg.

When it can be worn it is a good leg for a horseman, as the absence of the steel knee-joint makes it much more convenient for the saddle than the No. 8.

No. 13. Prostheses for Syme's Amputation.

The *sine qua non* of a good stump after Syme's amputation is capacity for complete end bearing. Therefore there is no necessity to design the prosthesis so as to take much weight on the sides of the stump, or under the tuberosities of the tibia or head of the fibula. Still less necessary is it to carry any part of it above the knee, for, owing to the bulbous shape of the end of a typical Syme stump, it can be gripped in the narrow part above the end, and so prevent the prosthesis from slipping down when the foot is lifted off the ground.

Prostheses for this amputation may be divided into three types. These are: (1) The older pattern, in which the whole stump is encased in a stiff leather socket, and the movements of the foot are limited by an adjustable leather tendo Achillis, and by an elastic dorsiflexor in front of the ankle. (2) The new patterns, without tendons, in which movement is limited by two rubber buffers, one of which is compressed on dorsiflexion and the other in plantar flexion. These rubber buffer legs may have complete closed-in sockets of stiff leather as in fig. 212, or only a stiff leather front with a pliable leather flap coming around the back of the stump as in fig. 213.

In all cases the socket is strengthened by two or more steel plates, of which one on each side enters into the ankle-joint.

The limb maker, in designing a Syme prosthesis, finds himself strictly limited as regards the space at his disposal. The level

FIG. 212.—W. R. GROSSMITH'S PROSTHESIS FOR SYME'S AMPUTATION. Complete socket opening at one side.

at which the leg bones are sawn off varies, but the average distance from the bottom of the stump to the ground, when the patient is erect with the pelvis level, is only 2½ inches. It may be as little as 2 inches or as much as 3 inches. Into this space, therefore, the artificial foot and ankle-joint and the lower wall of the socket or a platform, if one is used, must be compressed.

Some makers, to save space, do without the lower end of the socket and use no platform, so that the end of the stump rests on the top of the foot. This is a bad method, because every movement at the ankle-joint must cause friction between the end of the stump and the top of the foot.

The end of the stump should always rest upon a surface which is rigidly connected with the upper component of the ankle-joint, and which moves with it and with the stump, and not with the lower component and the foot.

Whatever type is adopted, the stiff leather socket, whether partial or complete, should fit the whole extent of the stump closely, and it is best to mould it upon a plaster cast. In a long

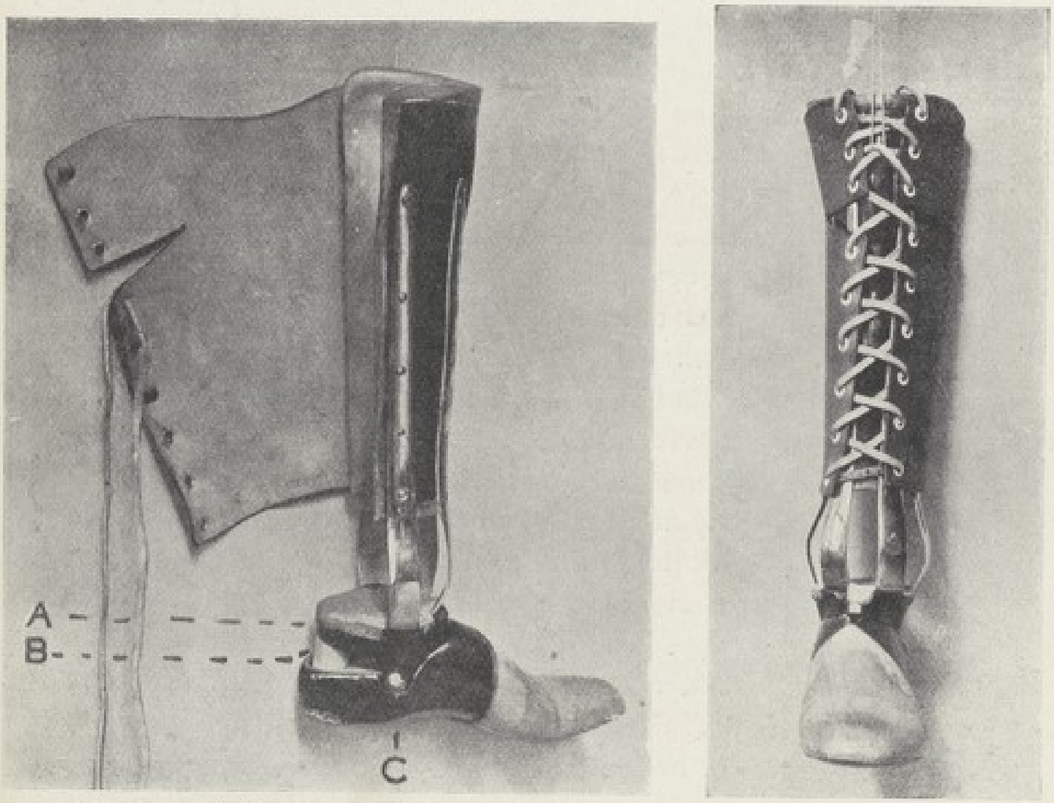


FIG. 213.—"ESSENTIAL" PATTERN LIMB FOR SYME'S AMPUTATION.
A, The platform; B, the heel rubber buffer; C, the ankle bolt.

Syme stump the remains of the malleoli on each side may be hypersensitive to pressure, and here the socket should be slightly bulged out beyond the lateral surfaces of the end of the stump (see fig. 213).

When the complete leather socket is used with rubber buffers instead of tendons, the side steels which articulate with the foot carry steel buffer plates behind and in front, which press upon rubber buffers resting on or partly imbedded in the top of the foot. This type of prosthesis has not stood wear as well as the type next to be described, which is to be preferred if a rubber buffer action is required.

The type of prosthesis with an incomplete socket, which was introduced from the United States by the Essential Artificial Limb Company, has given great satisfaction to a number of amputees. This limb has a half socket of stiff leather moulded upon a plaster cast, and extending from the tuberosities of the tibia to 1 inch or 1½ inches above the end of the stump. This half socket covers the anterior half of the upper four-fifths of the stump only. The rest of the stump is enclosed and kept pressed forward into the half socket by means of two pliable leather calf pieces, which go round the back of the stump to be laced in front to the half socket (see fig. 213).

Four steel plates are riveted to the moulded leather, and below are fixed by screws to the wooden platform, which resembles in shape the ankle base of an above knee leg. The two lateral steels are prolonged beyond the platform, and are riveted to the ankle bolt, on which an ankle staple plays. The rubber buffers and bushing, etc., are similar to those in the standard foot, from which this foot differs in that it is much lower, in consequence of the small space available for the platform, ankle-joint, and foot.

In rare cases of unusually low site of Syme's amputation it may be impossible to fit a foot of any of the above types without making the limb too long, and so tilting the pelvis. If this is thought to be objectionable, the level may be easily restored by adding to the boot heel of the sound side. If the difference is more than ½ inch, appearances will be improved by taking half the difference off the heel of the amputated side, and adding a like amount to the heel on the sound side. This difficulty does not exist in the case of double Syme's amputations—often from frost-bite—which are dealt with in the section on double amputations.

Pirogoff's amputation has been very seldom performed in the British services, fortunately for all concerned. The resulting stumps are too long to allow any ankle-joint to be used. A socket similar to that for Syme's amputation should be fitted, with side steels attached to a sponge rubber foot, or a wooden foot with the toe-joint situated farther back, and allowing more movement than usual, so as in some measure to take the place of an ankle-joint.

As the result of sepsis and other complications there are, unfortunately, among the men mutilated in the late war, a number whose Syme's amputation stumps are too sensitive to take enough end pressure to enable them to wear the typical prostheses without transferring some of the pressure above the knee. Such cases would be best reamputated in the middle of the leg, but not all will consent to this proceeding.

For such, No. 16 prosthesis is provided. This differs from the ordinary Syme type by having the steel plates carried up to form the lower components of knee-joints attached to a thigh corset, as in the No. 8 limb. It may even be necessary in some cases to order a blocked leather corset taking a bearing under the tuberosity of the ischium.

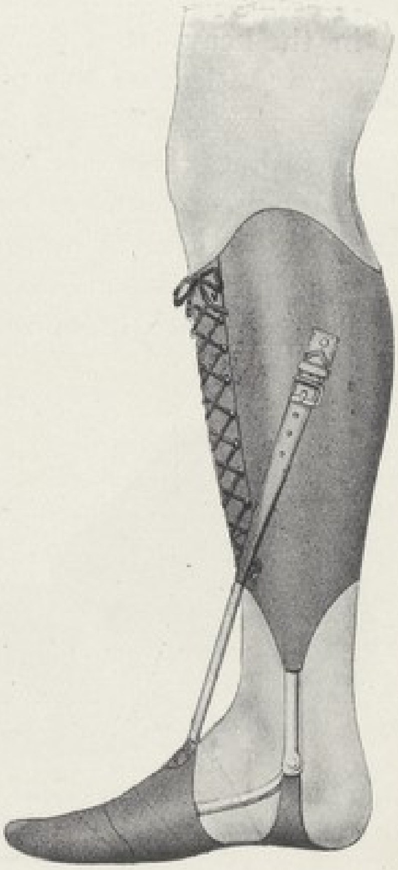


FIG. 214.

NOTE.—Prosthesis for amputation of the foot, by H. V. Duncan. The stump here shown is longer than a "Chopart," but the prosthesis is suitable to the latter.

No. 18. Prosthesis for Chopart's Amputation.

The problem of fitting a satisfactory prosthesis for Chopart's amputation presents considerable difficulty. The stump is too long to allow of anything more than a thin plate being placed under the plantar surface, yet the tarsal stump is too short for any appliance to be attached to it without including the ankle, and seriously hindering or preventing movement in that joint.

Two types of prosthesis are used; the one (No. 18) suitable for hard work consists of a steel sole plate with lugs at the sides which articulate with two side steels, to which is riveted a leather combined leg corset and anklet laced together in front. A leather tendo-Achillis and a spring dorsiflexion strap are fitted, as in the case of the tendon pattern Syme's foot. To the upper surface of the sole plate in front of the end of the tarsal stump is fixed a block of cork modelled to fill out the boot, and the whole is covered with soft leather. As the scar is often situated on the front of the stump, a layer of sponge rubber should be cemented to the back of the cork block where it comes in contact with the stump.

The other type of prosthesis has no steel joints, but consists of a stiff flexible leather sole piece with a soft leather laced anklet. The missing part of the foot is either represented by a cork block, as in the heavy type, in which case movement is effected by bending the leather sole piece, or, instead of the cork block, a wooden fore-foot is used with a hinged toe-joint placed as far back as practicable (see fig. 215).

In all the prostheses for Syme's, Pirogoff's, and Chopart's amputations little or no provision can be made for ventilation; consequently, not only does the amputee suffer discomfort, but the leather, and still more the steel parts, are quickly corroded,

Fig. 215.—Light Prosthesis for Chopart's Amputation, by Messrs. J. and E. Ferris, London.
See note under fig. 214.

although attempts are made to preserve the latter by nickel-plating or painting with an elastic bituminous varnish.

Another drawback is the necessity for specially made boots to accommodate the bulky apparatus, which of necessity is larger than the normal ankle. With some types of Syme prostheses, such as the Essential pattern, ordinary low shoes can be worn, but for the Chopart appliances specially made boots or shoes are necessary.

For Lisfranc's amputation and all less extensive mutilations, a boot with the fore part filled out with cork, with a sponge rubber cushion behind it, is all that is necessary.

All three amputations were probably first introduced with an eye to fitting stump (or elephant) boots, and not complete artificial feet, for which they are not well suited. Chopart's amputation in particular seems to have been intended for a stump boot (see Chapter XII. on Peg Legs). But the British amputee of the Great War is seldom satisfied with them, for, as a rule, he attaches an exaggerated importance to appearances.

There is no doubt, moreover, that, as already explained, the artificial foot, if not too freely flexible at the toe and ankle, makes the gait more secure and more natural in appearance.

Stump socks of woven or knitted woollen material are worn on all stumps of the lower extremity, except in cases of disarticulation at the hip, for which the underclothing generally suffices.

They are made of various sizes for the different amputations, and should fit closely without wrinkles, but not be tight enough to interfere with the cutaneous circulation.

For amputations above the knee, the socket, if it fits properly, will only allow one sock to be worn, but for amputations below the knee taking a No. 8 limb it is generally best to allow for two socks.

In all sockets, knee, and shin pieces, in which there is a clear space below the end of the stump, openings for ventilation should be made, one on each side. They should be of oval form, and in a thigh socket for a short stump may be as large as 2½ inches by 1 inch. Not only do they help to cool the stump by allowing evaporation, but they are also of use for inspection of the relations between the stump and the socket, and for adjustment of the stump sock.

For this purpose a tape is tied and stitched to the lower end of the sock. When putting on the leg, this tape is passed into the top of the socket, and out through one of the holes. As the stump is thrust down into the socket the tape is pulled upon firmly by the hand, and then tied loosely round the limb. The object of this manœuvre is to prevent the skin from being dragged upwards on the stump as the latter is pushed down. Such dragging may cause the skin over the end of the bone to be compressed against it, and its nutrition interfered with, so as to cause ulceration. The danger of this is the greatest when there is an end scar adherent to the bone.

End bearings have been discussed in Chapter II. An end bearing pad consists of a piece of sponge-rubber, which is supported on a leather thong, which is laced through half a dozen small holes in the socket below the end of the stump so as to form a lattice work. The amount of pressure between the stump and the pad can be easily regulated.

CHAPTER XVI

ON THE LENGTH OF LEG PROSTHESES AND ON APPLIANCES, ETC.

THE relative length of limbs is estimated, as in cases of deformity, by comparing the position of the anterior superior iliac spines. With practice it becomes possible to say with certainty whether the pelvis is level or no by so small a difference in the height of the two spinous processes as ¼ inch, but to do this certain precautions must be observed. The patient must stand on a level surface with the feet together and both knees fully extended, exactly in front of the surgeon, who should be seated in a low chair with his shoulders parallel to the patient's hips, so that his eyes when he bends forward are nearly on a level with the anterior superior iliac spines. He then should place one of his thumbs horizontally on each side of the pelvis, so that with its upper border he feels the most prominent part of the bony process. The exact point does not matter, as long as the two thumbs are in similar positions on the two ilia. If the surgeon is not seated directly opposite the patient, he is likely to over-estimate the height of the more distant thumb.

In theory an artificial leg should be of the same length as the sound one, or, in cases of double amputations, of its artificial fellow. In practice it is found convenient in cases of above knee amputation to make the artificial shorter than the natural limb by about ½ inch. This shortening enables the amputee to clear the ground and to walk upstairs, uphill, or on a side slope, such as the usual town foot pavement, more easily. There is no need to fear the development of serious spinal deformity from the use of a short leg. Unfortunately we are all familiar with the imperfect results of the cure of tuberculous disease of the hip-joint, which too often leave patients with an adducted thigh as well as an ankylosed hip. Adduction is then compensated by a tilting up of the pelvis on the affected side, and necessarily by a lateral curve of the lumbar region of the spine; yet, even in cases of tilting to the extent of several inches, no more deformity of the spine occurs than is necessary to compensate for the tilting of the pelvis, even after many years, and no ill-effects result.

When the question arises as to whether the prosthesis is to be shortened or lengthened, as the case may be, the trial boot devised and patented by F. G. Ernst is of great value. This simple appliance consists of a leathern sandal which can be fastened to the patient's boot by means of straps, and into which the necessary number of measured leather soles may be slipped. The sandal itself is $\frac{1}{8}$ inch thick, and soles of $\frac{1}{8}$, $\frac{1}{4}$, and $\frac{1}{2}$ inch are provided, so that when all are inserted the limb is lengthened 1 inch.

In cases in which the question of shortening the prosthesis arises, the boot is put upon the sound limb, but in cases of lengthening, on the artificial limb. The patient is told to walk in this on the level, on slopes, and up and down stairs, and a decision come to on the surgeon's observation and the opinion of the patient himself.

This method saves many needless alterations in the length of limbs.

A below knee limb should be of the same length as the natural one, unless there is some disability of the latter, which is helped by making the prosthesis longer or shorter, as may happen in cases of ankylosis of knee or hip, or dropped foot, etc.

Before deciding that a prosthesis is too long, the surgeon should see that the stump is properly inserted in the socket, so that the latter is bearing on the right places. Sometimes patients who have had a limb for some time, and whose stumps have altered, to ease themselves will put on a number of stump socks, so that the stump is partly out of the socket and the pelvis on that side is tilted up. Care should be taken to see that only one sock is worn on a thigh stump, or one or two (according to circumstances) on a leg stump, before estimating length.

Pick-ups ; Anti-Biting Pads and Back Pads.

When a central knee control with shoulder braces is fitted to an above knee leg, one of the advantages aimed at and claimed is the prevention of friction between the braces and the patient's shoulders. The necessary movement should take place between the cords and the rollers. Some patients, however, find that the braces move on the shoulders and gradually slip upwards in front, thus bringing the hooks to which the cords are attached too high up in front and too low down behind. To prevent this, what is called a pick-up is fitted. This consists of a leather thong which passes through a leather loop attached to the front of the socket a little below the top, each end above being fastened to one of the hooks of the suspenders. An elastic pick-up has somewhat similar attachments, but different functions. It is used for short thigh stumps, and helps to bring the socket forward and to hinder its slipping down. It consists of a piece of elastic webbing bound at each end with leather, the binding at the upper end forming a loop, through which a thong passes to the suspender hooks. The lower end is fixed to the front of the socket by a screw or rivet some 4 or 5 inches below the top.

Fat or muscular patients often complain that the roller cords, which pass over the back of the stump, press too hardly on the buttock, where they may cause abrasions. To prevent this, a flap of stout leather is fastened with screws to the back of the socket just below the edge. This flap intervenes between the buttock and the cords, and has come to be known as an "anti-biting" pad. It would be better described as a "protecting flap."

Care has to be taken that the flap lies close to the socket, so that the skin of the buttock does not get caught and pinched between the edge of the socket and the flap, as will occasionally happen.

It is the practice of Messrs. J. F. Rowley to fit all above knee legs with what is called a back pad, as well as an anti-biting pad in suitable cases. The back pad covers the roller cords and the upper three-fourths of the posterior surface of the thigh and knee parts of the limb, and is fixed by four screws or rivets. It consists of two layers of felt enclosed in a thin leather cover. Its uses are to protect the trousers from the wear of the cords, and to afford a more secure seat upon a chair than is given by the smooth and rounded surface of the varnished raw hide. Such a back pad has been adopted by the Ministry of Pensions for the standard wooden limbs (see fig. 216).

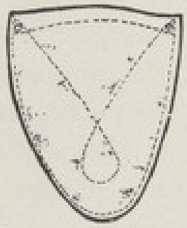


Fig. 216.—Back Pad.

Knee Locks.

Patients who have only short thigh stumps or weak stumps with which they have not good control of the knee, as well as patients whose occupation compels them to stand for a long time, find a knee lock of use to them. It is useful also to secure the knee from bending unduly or unreasonably in going downstairs. Many amputees, however, who did not feel secure without a knee lock when they first had prostheses, find after longer experience that they no longer require it.

The automatic knee lock of the articulated peg leg has already been referred to. It is a good lock, because the locking surfaces are end to end, and it cannot give way, as long as the pivot of the flute key holds, without severe damage to the wooden parts. It is, however, not designed for knee-joints in which movement occurs in walking. A knee lock must be strong and trustworthy, and it must not add much to the weight of the limb. The position of its handle must be convenient, and it must be easily cut out of action when required. It must not be possible for the lock to come into action of itself when it is not wanted. Knee locks which are worked from a position below the knee are inconvenient, and need not now be discussed.

A very strong lock is used for mortice-and-tenon knee-joints. In this the tenon is prolonged above the knee bolt. On the top of the prolongation a slot faced with steel is made. A square steel bar, which extends right across the knee piece and is held in slots on both sides, can be slid down into the slot on the tenon. To the outer end of the bar is attached at right angles a short handle which lies against the side of the knee piece and socket. As this bar is held at both ends the lock is very safe. The bar is kept from dropping down when not required by means of a small friction spring.

After much consideration and many experiments the Ministry of Pensions has decided to standardize a knee lock on the same principles as that long used by Messrs. J. E. Hanger and Co. This latter is a simple but strong lock, which consists of a round steel bar which passes down through a steel plate in front of the knee piece, and when the leg is fully extended enters into a staple on the posterior or internal surface of the front of the shin piece. The handle, consisting of a round knob of wood, lies on the outer side of the upper part of the thigh socket, and the shank to which it is attached runs through a guide plate on the socket, and, being suitably cranked, passes through the outer ventilation hole to the interior of the knee piece. The knob can be easily grasped by the fingers through the clothing or from the inside of the trouser pocket.

This lock has, however, one drawback. It may become loose in the guide plate, so that it may slide down of its own weight, or on a very slight unintentional push, when the knee is flexed, and become jammed between the outside of the shin piece and the knee piece on attempt at extension, and so cause a fall and damage to the leg or, still worse, to its wearer. This defect has been overcome in the standard lock by the addition of a spring, which catches on the guide plate and can only be released by an effort. The shank of the lever, instead of being round, is oblong in section (see Appendix, fig. 266).

Much ingenuity has been expended in devising automatic knee locks which should only come into action when the need arose—that is to say, when weight is put upon the limb. Some of these are intended to lock the knee even when it is flexed; others only when it is fully extended. All are intended to release the joint as soon as it is unloaded.

The simplest is that introduced by the Gale Artificial Limb Company, which may be described as something like the Hanger lock turned upside down. There is a similar perforated steel plate in the end of the knee piece, but the rod enters it from below instead of above, running from the heel of the artificial foot through guides in the shin piece to the knee. The lower end is connected with a plunger in the lower surface of the heel. When the patient stands on the heel, and as soon as the knee is extended, the rod is pushed up into the knee piece and locks the joint. It is withdrawn by a spring as soon as the heel is relieved of weight. Some amputees have found this lock useful. The greater part, however, prefer a lock more under their control, with which they can keep the joint locked or unlocked whenever and as long as they wish.

Other more elaborate locks on the band-brake principle, or a mercury balance, or tumbler mechanism, have been introduced, but amputees' experience is not in favour of them, chiefly because of the uncertainty of their action and in some cases on account of their weight.

Protection of Clothing.

Artificial limbs, which present hard surfaces, metallic projections, cords and straps and buckles, cause much more wear and tear of the clothing than does the natural limb. Much of this is inevitable, but it may be minimized by the use of leather protecting flaps over metallic joints and buckles, and over the gaps formed when joints, such as the ankle, are flexed or extended.

Stockings and socks on an artificial leg find themselves squeezed and rubbed between two hard substances—the artificial foot and the boot—and suffer accordingly. Boots often have prominent nails inside, especially at the heel. As the patient is not reminded of these by pain, as he would be in the case of a living foot, he ignores them until they have not only worn the stocking, but often have inflicted considerable injury upon the heel of the artificial foot.

Some patients who wear limbs with pelvic bands find that a loose hanging apron of thin leather, attached to the band, is useful to protect their clothing from the friction of cords and straps.

In other cases it is found advisable to line the trousers opposite prominent parts of the prosthesis with chamois or other pliable leather.

CHAPTER XVII

ON THE WEIGHT OF PROSTHESES AND ON METAL LIMBS FOR THE LOWER EXTREMITY

THE writer has always maintained that prostheses, especially those for the lower limb, cannot be too light, provided they are strong enough; and when entrusted in February, 1917, with the duty of examining single-handed all the amputees who passed through Queen Mary's Convalescent Auxiliary Hospital at Roehampton, he took steps to have all limbs weighed, and provoked competition among limb makers in lightening them. A marked reduction of the average weight of the various types of limbs followed, and the competition of light aluminium legs still further stimulated progress in this direction.

The actual weight of the limb upon the scales is itself a very important factor, but still more important is the distribution of the weight. It should be the aim of the designer and manufacturer to lighten not only the whole prosthesis, but to raise the centre of gravity as much as possible, remembering that 1 ounce at the end of a 2-foot lever of the third kind needs as great an effort to raise it as would lift 4 ounces at a distance of only 6 inches from the fulcrum. In most complete artificial No. 3 limbs the centre of gravity is situated about 3 inches below the centre of the knee bolt. In permanent peg legs it is often found to be at or about the knee bolt.

However light a limb may be, it will not feel so if it fits badly. As a patient with a short thigh stump put it: " When the socket fits me properly the limb feels no weight at all, but when it is too loose " (owing to shrinkage of the stump) " it seems to weigh a ton."

Too much reliance must not be placed upon the weights given for limbs in the advertisements of manufacturers and traders, describing the particular type of limb they supply. The statements made apply only to the individual limb advertised, and some margin of weight should be allowed for.

It is usually found that the weight of limbs made for actual patients and worn by them differs considerably from these specimens.

The statements made in this chapter as to weight are based upon observations made upon prostheses in actual wear, which were weighed by the writer personally or under his direction. It should be noted that the weights of limbs here recorded are net. That is to say, that they are weighed without socks, boots, or shoes, and generally without suspenders.

The higher up the site of amputation, the more the weight is felt, and it is chiefly for short thigh stumps that very light limbs have shown their superiority. Some amputees with below knee stumps do not like very light limbs, and some with medium thigh stumps even prefer the rubber foot, when they have become used to it, to a wooden one ½ or ¾ pound lighter. In this, as in other particulars, the idiosyncrasy of the patient is seriously to be reckoned with.

Light metal limbs made of an alloy of aluminium were just beginning to be used when the war broke out. The first prosthesis of this kind which was seriously worth notice was made for himself by an engineer who had the misfortune to suffer an amputation of the thigh after an aeroplane accident. The limbs since put upon the market by him have been very successful, but their price—about three or four times as much as that of wooden limbs—prevented the War Office and later the Ministry of Pensions from authorizing their general issue.

The material of which they are made and their consequent lightness are not their only peculiar characteristics. This limb is not fitted with an active knee control, but its designer has reverted to earlier methods, by which the knee is controlled by the stump and pendulum action. By making the knee-joint stiffer in movement than has generally been customary, the shin piece is prevented from swinging backward so far as with a loose knee, and, therefore, has less angular distance to travel before it is fully extended again. Hyperextension is prevented by a back check, which acts instead of a buffer.

The old principle of placing the centre of the movement of the knee-joint and the knee bolt as far back as practicable is carried out to the full, so as to minimize the risk of the knee giving way forwards. This is shown in fig. 218, which is a view of the interior of the socket. The thigh socket and knee piece are all in one. In the case of bulky stumps this constitutes the socket, which is fitted to the stump. In the case of shrunken stumps appearances are preserved by the use of an inner socket of

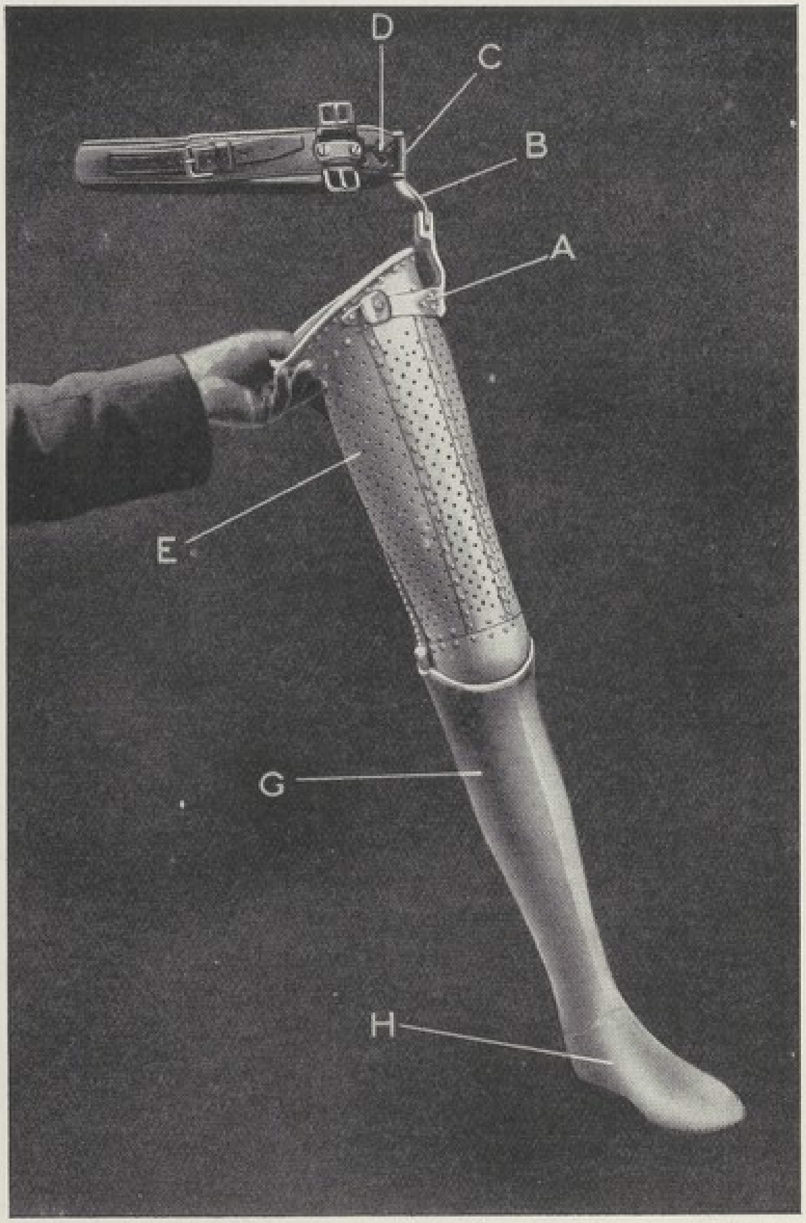


FIG. 217.—DESOUTTER LIMB.
A to D, Snivel pelvic band and hip-joint allowing free movement; E, outer casing of thigh; G, padded shin piece; H, foot without ankle-joint.

perforated metal; which is fixed into the thigh piece, the latter being made to match the living limb, as is the case in fig. 217. This arrangement allows, in the case of short stumps, of some accommodation of contractions of the hip by tilting the internal socket.

The back of the knee part is strengthened inside by two transverse flanges of metal, the upper one of which is seen in the

FIG. 218.—INTERIOR OF SOCKET OF THE DESOUTTER LIMB, SHOWING (IN WHITE) THE KNEE-BOLT CASING, AND BELOW THIS ONE OF THE STRENGTHENING FLANGES.

figure. (This flange and the knee-bolt casing have been whitened in order to make them distinct.)

Fig. 219 is a side view of the limb in full flexion. In this position there is a somewhat unsightly projection of the knee,

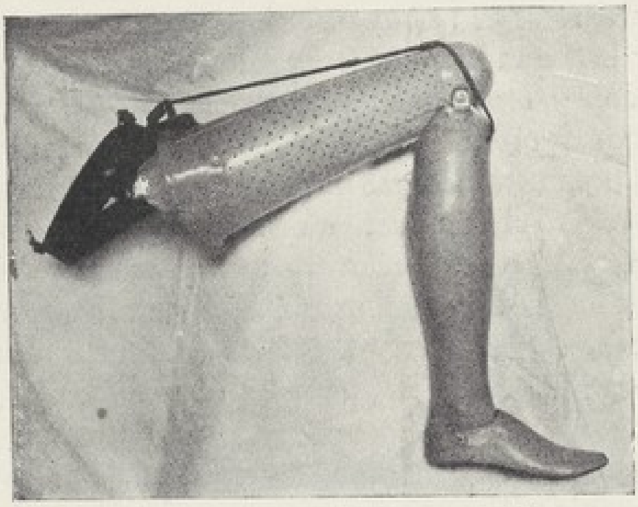


FIG. 219.—DESOUTTER LIMB FULLY FLEXED.

and a wide gap between the knee and shin pieces. Both socket and outer casing are perforated in order to save weight and to ventilate the stump. This figure illustrates the drawback of the method of attaching the knee extension strap to the pelvic band. On flexing the knee the band is tilted down in front, despite the shoulder strap. The weight of the limb from which this photograph was taken with the pelvic band is 5 pounds 7 ounces. For longer stumps, to keep the prosthesis from slipping off the stump, a special form of pelvic band is fitted, which is designed so as to interfere as little as possible with free movement at the hip-joint. This consists of a horizontal semicircular plate of metal, pivoted by its ends to the front and back of the thigh piece, the outer half of which it embraces without touching it except at its ends. To the middle of this an upright rod is hinged, the axis of the hinge being transverse or coronal. The upper cylindrical end of the rod is received into a vertical tube fixed to a light steel pelvic band. A brief consideration of this description, and reference to the figure, will show that movements of adduction-abduction are allowed by the pivots on the back and front of the thigh, flexion and extension by the hinge-joint on the outer side of the semicircle, and rotation by the tubular joint on the pelvic band. No movement is very much hindered by this mechanism, except downward movement of the socket off the stump, but the axis of the rotation joint does not correspond to the centre on which rotation takes place in the natural hip-joint, seeing that it is placed considerably further outwards; consequently, rotation movements must be restrained to some extent. The band serves in effect the same purpose as the leather belt and loop, which has long been used for peg legs and occasionally for complete prostheses (see fig. 217).

It does not answer the same purpose as the standard pelvic band and hip-joint, which was introduced by Ernst for short thigh stumps to prevent circumduction and undue abduction—in short, to confine movement to flexion and extension only, and to afford a fixed point for the attachment and a fulcrum for the movements of the prosthesis. For very short thigh stumps a steel pelvic band and hip-joint of the standard type has to be used, as shown in fig. 219.

As originally made, the Desoutter limb had no ankle-joint, but a movable ankle with rubber buffers has since been introduced. At the time of writing (June, 1921) this limb is only made for amputation of the thigh.

When light aluminium legs were first introduced, weight, which for a thigh amputation with the necessary pelvic band averaged about 5 pounds, gave them a great advantage over wooden limbs for similar stumps, of which the average weight was about 7 pounds.

Nevertheless, the old Anglesey type of leg for thigh amputation can be made as light, or even lighter, than any metal limb yet produced, and, except for heavy work, is at least as durable as any prosthesis of more modern design.

Improvements in the direction of lightness have since been made, so that the No. 3 standard limb made with the steel parts issued by the Ministry weighs only 5 pounds, and the No. 2 limb with a steel hip-joint and pelvic band weighs about 6 pounds. If duralumin were used instead of steel, the weight would be still further reduced, but for the hard wear and rough treatment to which many pensioners' limbs are exposed, duralumin for joints and bands cannot be relied upon. For professional men, clerks, and those engaged in sedentary and light occupations, it is strong enough when properly employed, and with all surfaces which are exposed to metallic friction protected by steel faces or leather or fibre washers.

During the years of the war the " tilting table " limb for hip-joint disarticulation proved better than anything that had been in use before, and many amputees were able to walk comparatively long distances on it, although it weighed on the average over 9 pounds.

On the other hand, many, finding the prosthesis too heavy, gave up its use and reverted to crutches.

To meet the demand for a lighter prosthesis, attempts were made to provide a satisfactory limb by using celluloid or a like material for the pelvic socket and thigh and shin pieces, and duralumin for the metal parts on which all the weight was borne. Even when duralumin was substituted for celluloid in the thigh piece, the saving in weight was not enough to counterbalance the drawbacks of clumsiness, difficulty of adaptation, and lack of durability.

The light metal No. 1 limb made by J. E. Hanger and Co. at Roehampton is at present the lightest and most satisfactory limb for disarticulations at the hip-joint.

This prosthesis has a pelvic socket made of moulded leather, as in the standard limb, but the remainder of the limb is made of sheet duralumin (see fig. 220).

Sheet metal is not so easily shaped to the outlines of a stump as is wood. It frequently happens that after a socket is made and fitted, and is apparently comfortable, a few days' actual wear discovers points of undue pressure or friction. A skilled fitter, by removing a little material in the appropriate situations, is generally able to put matters right.

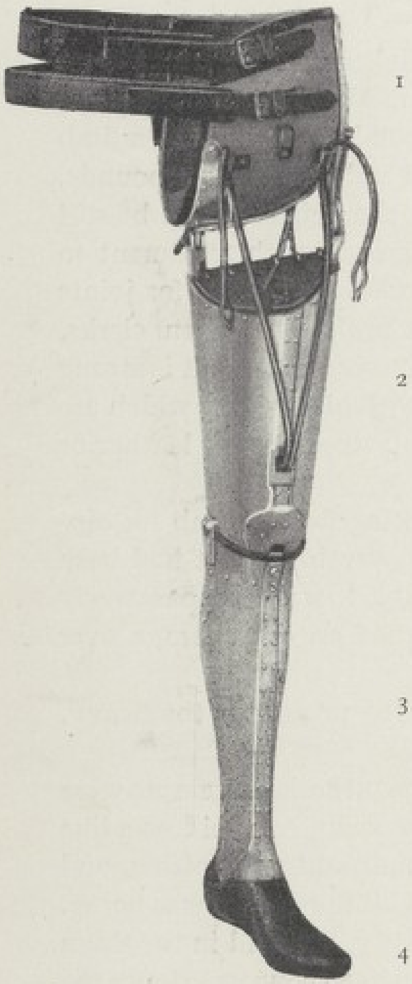


FIG. 220.—NO. 1 LIGHT METAL LIMB BY J. E. HANGER AND CO., LTD.

1, Leather socket; 2, metal thigh piece; 3, metal shin piece; 4, wooden foot.

In the case of a metal socket, it is true that it can be hammered out here or there, but with nothing like the accuracy possible in the adjustment of the wooden socket. It must be remembered, also, that the more an aluminium alloy such as duralumin is hammered, the harder and more brittle it becomes.

The manifest advantages of wood have induced limb makers to combine the wooden socket with a duralumin knee piece and shin and ankle.

Figs. 221 and 222 show limbs of the type made by J. E. Hanger and Co., Ltd. The No. 3 limb of this type weighs about $4\frac{1}{2}$ pounds, and has proved satisfactory as far as present experience goes.

As the outcome of experiments made in the Experimental Workshop of the Munitions Inventions Department of the Ministry of Munitions, which workshop was taken over and is now carried on by the Ministry of Pensions, sockets made of Certus glue, muslin, and celluloid, were produced as stated in the section on the upper extremity. This material for convenience' sake is called "Certalmid."

The prosthesis for the lower extremity designed and constructed in the workshop has a socket made of this material, which is lighter than a wooden socket of the same size and strength, and has the advantage of having no grain and not being likely to split as wood does.

At the same time it can be ventilated by numerous perforations without unduly weakening it. If due precautions are taken in manufacturing these sockets, there will be no tendency

Fig 221. Fig. 222.

FIG. 221.—No. 2 LIGHT METAL LIMB, BY J. E. HANGER AND CO., LTD.
FIG. 222.—No. 3 LIGHT METAL LIMB, BY J. E. HANGER AND CO., LTD.

1, Wooden socket; 2, metal thigh piece; 3, metal shin piece; 4, wooden foot.

to separation of the laminæ of which it is built up, but if the layers are not properly dried and each successive one closely bonded with the former one, separation may occur. Prevention of this is easy with due attention to details. The method of making these sockets is described in the Appendix.

The design of the remainder of the limb departs widely from the stereotyped forms, based upon the use of wood, which have prevailed for so many years.

Two main principles appear to have been acted upon—one that of such standardization as will allow of mass production of the greater part of each limb, thus much reducing cost, and the other the concentration of material on the lines and at the points of strain, leaving none at all where it is not required, and thus saving weight. The result is a " scaffolding " limb, of which the shin piece is formed of four uprights and three flanged rings of duralumin, the knee is a duralumin cup, and the thigh piece is formed of four uprights and one flanged ring of the same metal just above the knee. The four uprights are riveted to the Certalmid socket.

If the knee-joint and thigh and shin parts are made up in the factory, all the limb fitter has to do is to cut the uprights to the appropriate lengths, and, having made his socket, to rivet the thigh uprights to it and the leg uprights to the ankle ring, taking care that the lower ends of the latter are bearing upon the ankle plate and not only on the rivets. To increase resistance to deformation by forces causing bending on the flat, the uprights are made of slightly curved cross sections. This shape not only increases their rigidity, but it enables them to lie snugly against the flanged rings, and avoids sharp edges, which would damage the clothing.

These principles have not yet been applied to limbs for dis-articulation at the hip except experimentally in one or two cases, for which they promise to be very satisfactory. The principle of metal scaffolding, which has been already referred to, lends itself well to the peculiar conditions of a No. 1 limb as regards the thigh piece, which, when of wood or even sheet metal, has to be so much reduced in front and behind as to be a source of weakness. In the Ministry limb all the strength can be concentrated in two lateral uprights, properly cross-stayed, thus allowing full flexion and making the sitting position easy. Like other prostheses for this mutilation, it has locks at the hip and knee.

The principle of a rather stiff knee-joint without shoulder controls, but with elastic knee extension strap, which has already

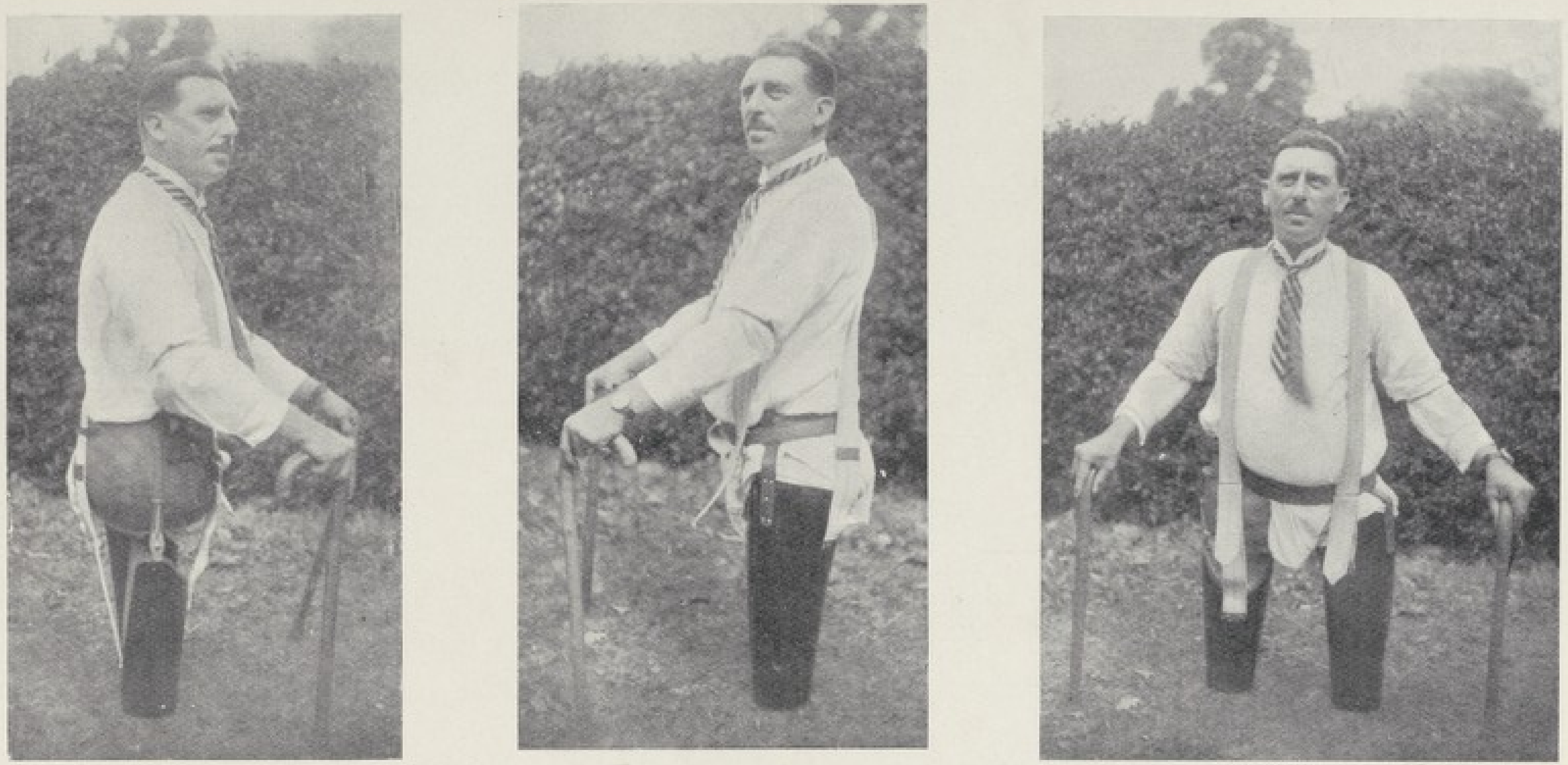
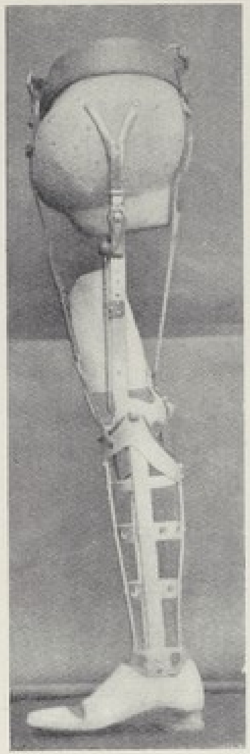
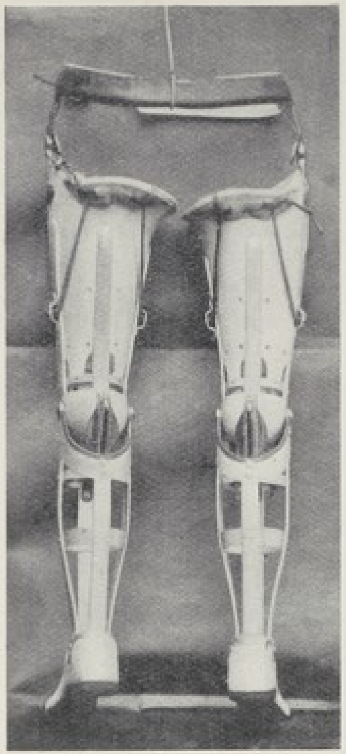


FIG. 227.—SHORT PEG LEGS FOR DOUBLE AMPUTATION: DISARTICULATION OF RIGHT HIP AND LEFT THIGH.
Despite this officer's severe disability he gets about well on his prostheses.

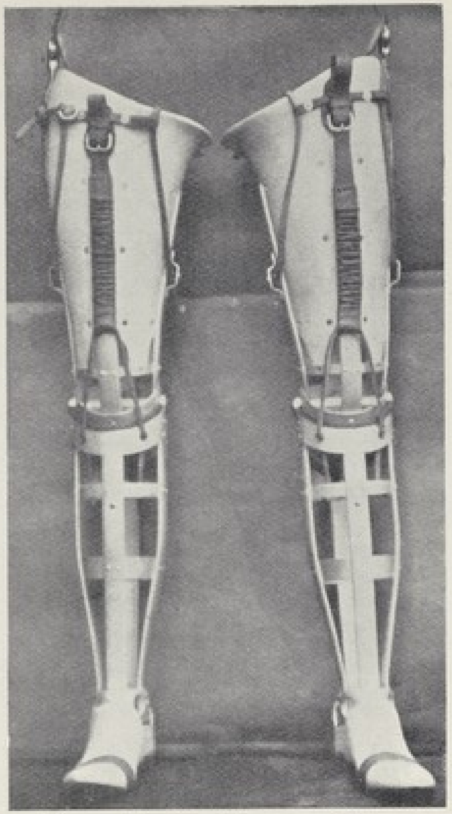
[*To face p.* 247.



No. 1.



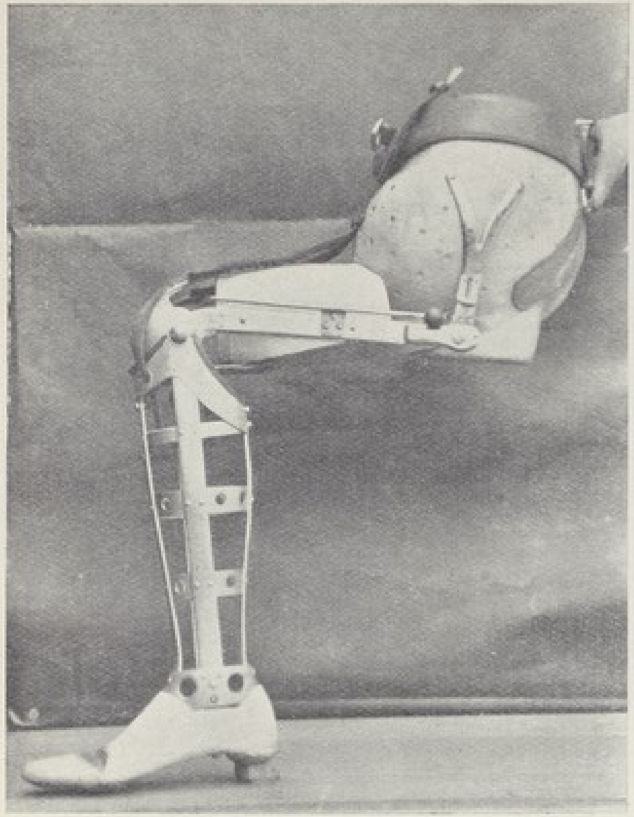
No. 2, for double amputation:
Back view.



No. 2, for double amputation:
Front view.

FIG. 223.—THE MINISTRY'S LIGHT METAL LIMBS.

[*To face p.* 245



No. 1, showing sitting position and cork pad, which rests on the chair.

Patient kneeling with No. 2 Ministry Light Metal Limb.

Patient walking with No. 2 Ministry Light Metal Limb.

FIG. 224.—THE MINISTRY'S LIGHT METAL LIMBS.

[To face p. 245.

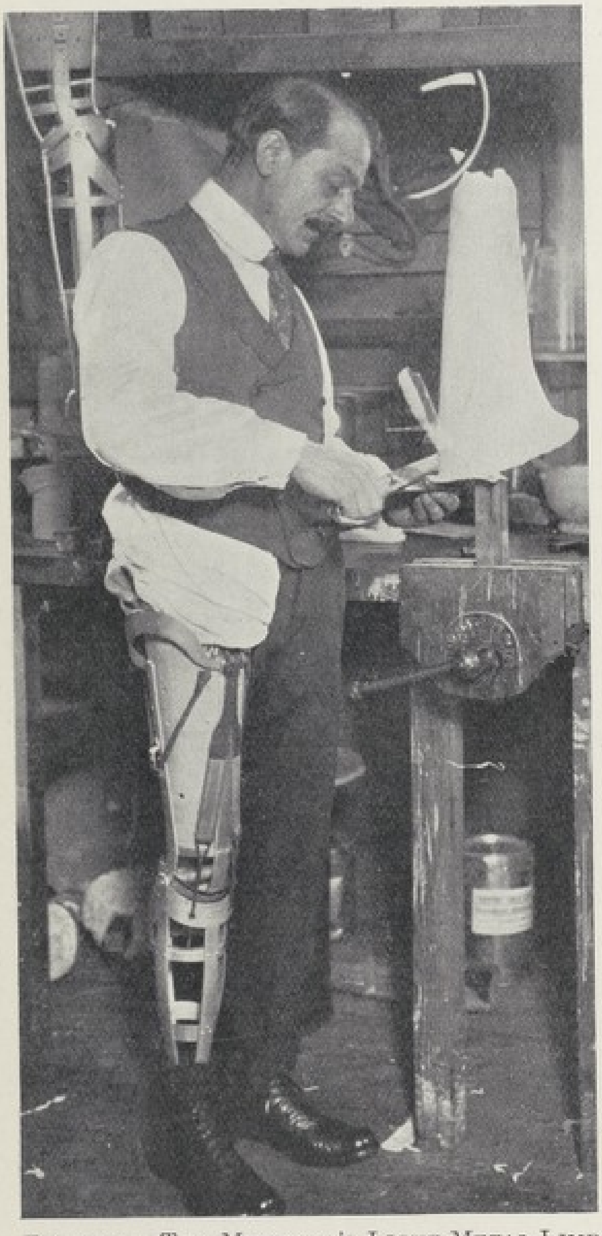


Fig. 225.—The Ministry's Light Metal Limb No. 2 in Use, fitted with Desoutter's Pelvic Band.

The wearer is engaged in adjusting a "Certalmid" thigh socket.

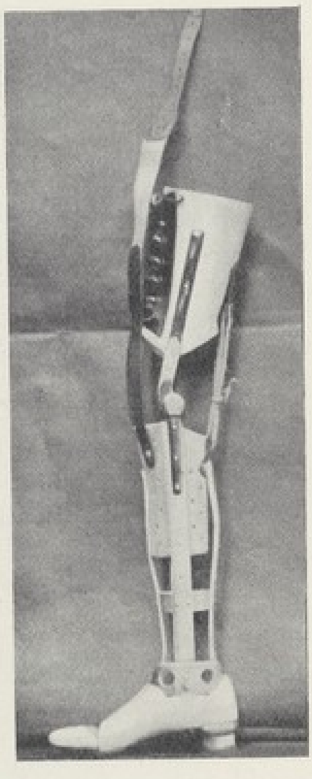


Fig. 226.—The Ministry's Experimental Light Metal Limb No. 8 for Below Knee Amputation.

[*To face p.* 245.

been described, is adopted as the standard for this limb, but for those who prefer the active shoulder control of the knee, control pulleys on the knee bolt and cords and suspenders are fitted. Hyperextension of the knee is prevented by an adjustable back check of flax threads covered with leather at the back of the knee. This renders any other buffer unnecessary. A knee lock is added when necessary. A very light but strong foot of cork, strengthened by vertical laminæ of wood, such as willow, glued together with Certus glue under pressure, and the whole covered with muslin and celluloid, has been made for use with this limb, and promises to be very satisfactory.

To meet the demand for a prosthesis for below knee amputations that shall be lighter than the standard type with wooden socket various attempts have been made. As far as the present writer's experience goes, the light metal limbs produced for such amputations have not been successful. Either they have not had any advantage in lightness or else the metal socket has not withstood the strains to which it has been subjected.

The Experimental Workshop of the Ministry of Pensions has, however, lately produced a prosthesis which is a modification of the type described as for amputations of the thigh, having a Certalmid socket made upon a plaster cast. This limb is about 1 pound lighter than the lightest standard limb with wooden socket, and appears to have an ample reserve of strength (see fig. 226).

NOTE.—Since Chapter XVII. was written, the Ministry of Pensions has suspended the manufacture of the Ministry's light metal limb. The Desoutter limb with a wooden socket is now issued to amputees who have short thigh stumps or other conditions which render a very light limb advisable.

CHAPTER XVIII

AMPUTATIONS OF BOTH LOWER EXTREMITIES

THE subjects of these mutilations are in a much less pitiable plight than those who have lost both hands. If the amputations are below the knees, with stumps of useful length many men are able to walk well and to cover considerable distances. Even patients with two long thigh stumps may be capable of very active locomotion, but the shorter the stumps the greater the disability.

Double amputations are not always symmetrical, and all possible combinations may be met with, such as disarticulation at the hip on one side, and a long below knee stump on the other, but such extreme discrepancy is rare.

In fitting double amputations, it is obvious that there is no absolute standard of length by which to settle the length of the prostheses, but, except in long stumps below the knee (including Syme's amputations), it is found advisable to fit limbs of such a length as to make the patient shorter than he was before his mutilation. By so doing, the leverage and the weight and the necessary effort required by locomotion are all reduced, and the patient is better able to reacquire the power of balance.

For below knee limbs 1½ inches reduction is enough, but in the case of two fairly long thigh stumps the height should be reduced 2, and in the case of short ones as much as 3, inches. This shortening destroys the proportions of the patient's figure, but the practical advantages of increased safety and activity outweigh æsthetic considerations. After a year or more's practice in the use of the prostheses it is in some cases advisable to lengthen the limbs 1 inch or more if the patient desires it. All cases of amputation of both thighs should be supplied with short peg legs as a preliminary measure for training and for use indoors. These consist of wooden sockets, in their upper parts exactly like those of the permanent prostheses, but terminating, at about the level where the knee-joint would be, in

FIG. 227.—SHORT PEG LEGS FOR DOUBLE AMPUTATION: DISARTICULATION OF RIGHT HIP AND LEFT THIGH.
Despite this officer's severe disability he gets about well on his prostheses.

[*To face p.* 247.

a solid circular end covered with sole leather or indiarubber. They are useful for such work as is done near the ground, as well as for domestic purposes. A bicycle repairer who asked for them found that they put him at a more convenient level for his occupation than he was before he lost his limbs, although he was, of course, too short for work at the bench. The stride with these peg legs is short, but this is only a slight disadvantage indoors (see fig. 227).

Double thigh amputations always need a pelvic band. This is generally made of one piece of steel, as in a No. 2 limb for a single amputation, but has a hip-joint riveted to it on each side. To facilitate putting limbs on and off they are made easily detachable at the hip-joints. There are two ways of doing this. In one the male and female pieces are connected by a thumb-screw with a hinged head instead of the ordinary screw. In order to disconnect the joint the wearer unscrews these, and replaces them after putting on the limbs and pelvic band. in the other a keyhole joint is used. A slot rather narrower than the diameter of the bolt is cut in a backward direction right through from the central bolt hole to the periphery of the male part of the joint. The bolt, which takes the place of the usual screw, is riveted into the female part so that it cannot turn. Its anterior and posterior surfaces are flattened, so that the width between them corresponds to the width of the slot in the male piece. The joint can only be connected or disconnected when the male piece and pelvic band are pushed backwards to a degree of hyperextension impossible for the wearer's spine. There is therefore no danger of detachment during use. When connected in the hyperextended position, the band is brought forward up to the pelvis and buckled (see fig. 228).

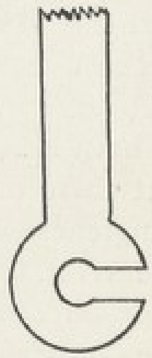


FIG. 228.—MALE PART OF HIP-JOINT, DETACHABLE BY MEANS OF KEYHOLE ARRANGEMENT.

The disadvantage of the keyhole method is that under the strain of hard use the metal of the male part yields and the slot spreads so that its sides are no longer parallel. This may occur to such an extent that the joint becomes partly disconnected and locks, or at least makes a noise in walking. If, to prevent this, the steel is tempered hard, fracture is likely to occur. In this joint also the effects of friction are soon seen, as there is no bushing, and all the wear is taken by only one half of the circumference of the bolt, the flat surfaces obviously escaping it.

Another method of facilitating application and removal of the prostheses is one which is used also for the pelvic bands of orthopædic walking instruments. Instead of a complete steel band, each hip piece is riveted to a short steel which stops short at a point $1\frac{1}{2}$ inches from the middle line of the back. These are padded and covered with leather in the usual way, and at the back as well as the front are joined by a strap and buckle.

It has lately been proposed instead of this to make a hinge-joint with vertical axis in the middle of the pelvic band steel, and this has been reported on as useful, but the writer has not yet seen this modification.

A large number, probably a large proportion, of amputations in both lower extremities are due to shell or bomb explosions, but there are a number of below knee cases due to frost-bite gangrene. These were pitifully numerous among the men of the West India regiments. The authorities who were responsible for sending these men to France in winter instead of to the campaigns in Africa and Asia were, no doubt, not consciously indifferent to needless suffering, even in men of colour, but they cannot be credited with imagination or common sense. These men proved to be very sensitive to cold, and some of them suffered from cold gangrene after two hours' sentry-go in the south of England during a mild winter.

The stumps, after amputation for frost-bite gangrene, are often, as already stated, poorly nourished and sensitive, and consequently difficult to fit. One West Indian with a Syme's amputation was unable to wear an artificial foot without the stump breaking down as soon as the temperature of the air fell to 60° F. Attempts to wear the prosthesis in England had to be abandoned, and he was sent back to Jamaica with instructions not to wear it till he reached the tropics.

CHAPTER XIX

PROSTHESES, ETC., FOR COMPLICATED AMPUTATIONS

Besides amputations of both lower extremities, among the amputees of the Great War are a certain number who have suffered the loss of one or both arms as well as one or both legs. The loss of a leg does not seriously affect the prosthetic treatment of an arm stump, but the loss or injury of an upper extremity in most cases handicaps the man who has lost a leg in his efforts to make good with a prosthesis. Most leg amputees, unless their amputation is very low down in the limb, have to use at least one stick, which is held in the hand of the side opposite to the amputated leg, so that the stick shall relieve the prosthesis of some weight and help the balance when the sound limb is raised from the ground in walking. The loss, for instance, of a right hand and a left leg is more disabling than the loss of a right hand and a right leg.

In some cases it is necessary to provide a stick with an attachment to the artificial arm, which will allow slight movement and yet be rigid enough to allow weight to be placed on it. Such is the stick appliance made by C. A. Blatchford. This is seldom of any use unless there is a good forearm stump.

To enable leg amputees whose hands are severely damaged to use a stick, two types of walking-stick are supplied, known as No. 7 and No. 8. No. 7 is intended to be used when the hand is useless for grasping purposes. A stiff leather case is strapped round the forearm to which steels are attached, which are carried down to the handle of the stick. The No. 8 stick is for less serious disability. A steel plate is screwed to the handle of the stick in such a position that the hand pushes down against it, so that it takes the weight and relieves the hand of the necessity of grasping the stick firmly. The wrist is encircled by a leather band with straps and buckles, which is riveted to the stick (see figs. 229 to 232).

In cases of flexed and stiff elbows it has sometimes been found necessary to fit a rigid leather arm and forearm casing or splint, on the lower surface of which a socket is fixed, into which a broomstick crutch end can be screwed. To transmit the weight properly this socket should be as nearly under the elbow as possible. While such an appliance is useful for walking, it is extremely inconvenient, owing to difficulty of detachment, when the wearer wishes to sit down.

A minor difficulty when a hand is lost is experienced in lacing up a thigh corset or a limb for Syme's amputation. In such cases straps or buckles are substituted for eyelets and laces, as

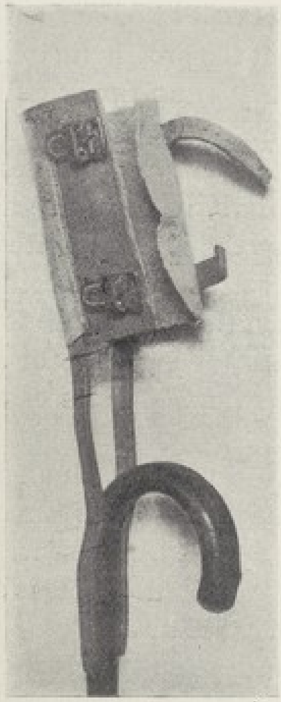


FIG. 229.—NO. 7 WALKING STICK.

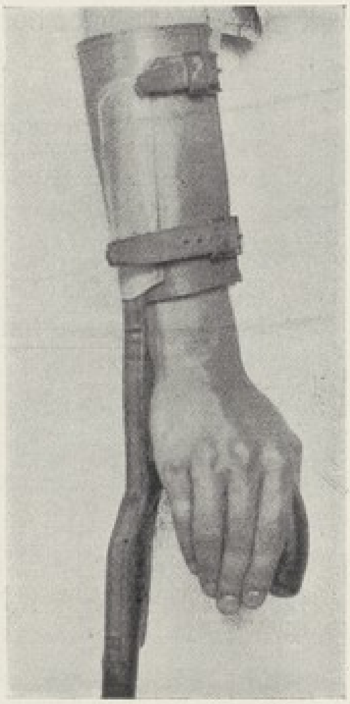


FIG. 230.—NO. 7 WALKING STICK IN USE.

Made by C. A. Blatchford.

they are much easier to manipulate with one hand. The buckles are most conveniently fixed on the side of the corset furthest away from the sound hand.

It is not within the scope of this book to describe every sort of prosthesis for unusual complications, but the treatment of those complications which are more often met with needs consideration. One of these is ankylosis of the hip-joint. In deciding which is the best position for ankylosis of this joint, we find ourselves between the horns of a dilemma. If the femur is fixed in extension the position is the best for locomotion, but it is extremely inconvenient and disabling in sedentary occupations. If, on the other hand, it is fixed in a much flexed position, locomotion, if possible, involves a severe compensatory lordosis, produced by hyperextension of the sacro-iliac joint and those of the lumbar and lowest dorsal vertebræ. These difficulties are familiar in civil practice among the subjects of hip disease, whose difficulties, however, are much smaller than those of the thigh amputees, since the former have unimpaired knee and ankle joints and the muscles to control them.

FIG. 231.—NO. 8 WALKING STICK.

FIG. 232.—NO. 8 WALKING STICK IN USE.

Made by C. A. Blatchford.

A careful balancing of advantages and disadvantages, backed by experience, leads to the decision that a position of moderate flexion is best—say of 30 degrees, measured by Thomas's method, as previously described. Slight abduction is also desirable. Supposing that the stump is short enough for the flexion to be accommodated in the formation of the socket, nothing further is needed, but in cases in which the stump is too long for this—say 9 inches or more—the difficulty is greater. By hyperextension of the lumbar spine and by curving the lower part of the socket and the knee piece, the knee-joint and shin piece may be brought back under the hip, so as to give stability and make locomotion possible. If the contraction is too great to allow of this accommodation—say over 45 degrees—and still more if there is much adduction as well as flexion, the operation of arthroplasty is advisable, and care should be taken in the after-treatment to keep the stump when at rest in the best position for ankylosis, in case the attempt to make a new joint fails. As a last resort osteotomy may be necessary. It is not possible to make rules as to the amount of contraction that can be accommodated, because the degree of mobility of the lumbar region of the spine varies greatly in individuals. One man with a contraction of 45 degrees will be able to compensate for it, while another with 30 degrees may be unable to do so. Generally speaking, youth and mobility go together, and *vice versa*.

The extended and only slightly flexed ankylosed thigh stump offers no difficulties to locomotion, but it affords a great obstacle to sitting down with comfort; and with an ordinary prosthesis, however well accommodated, the patient is unable to bend the knee so as to place his foot out of the way of other people. In these days of crowded public conveyances this is a great nuisance. By sitting well forward and on the corner of a chair, and at the same time flexing and thereby reversing the curve of the lumbar region of the spine, the sitting position is possible; but the thigh stump will then be directed downwards and forwards, and the knee will not be far enough from the ground to allow the shin piece to be bent under it. This may be remedied by the use of a very high stool, but that would only be available at home or in an office.

The difficulty is got over by providing an automatic locking joint just below the end of the stump. This joint is kept locked in walking, but the bolt or ring is pulled up before sitting down, thus allowing flexion forwards, producing an appearance as though the thigh were fractured. The annexed figures are from photographs of a limb made at the writer's suggestion by the Gale Artificial Limb Company. They clearly show the difficulty and the way in which it was met. This method of dealing with this complication has become the usual one at Roehampton (see figs. 233 and 234).

It will be noticed that the patient in the illustration has a knee lock, for use in going down stairs or when standing for long. For walking the knee is unlocked. A light metal limb with

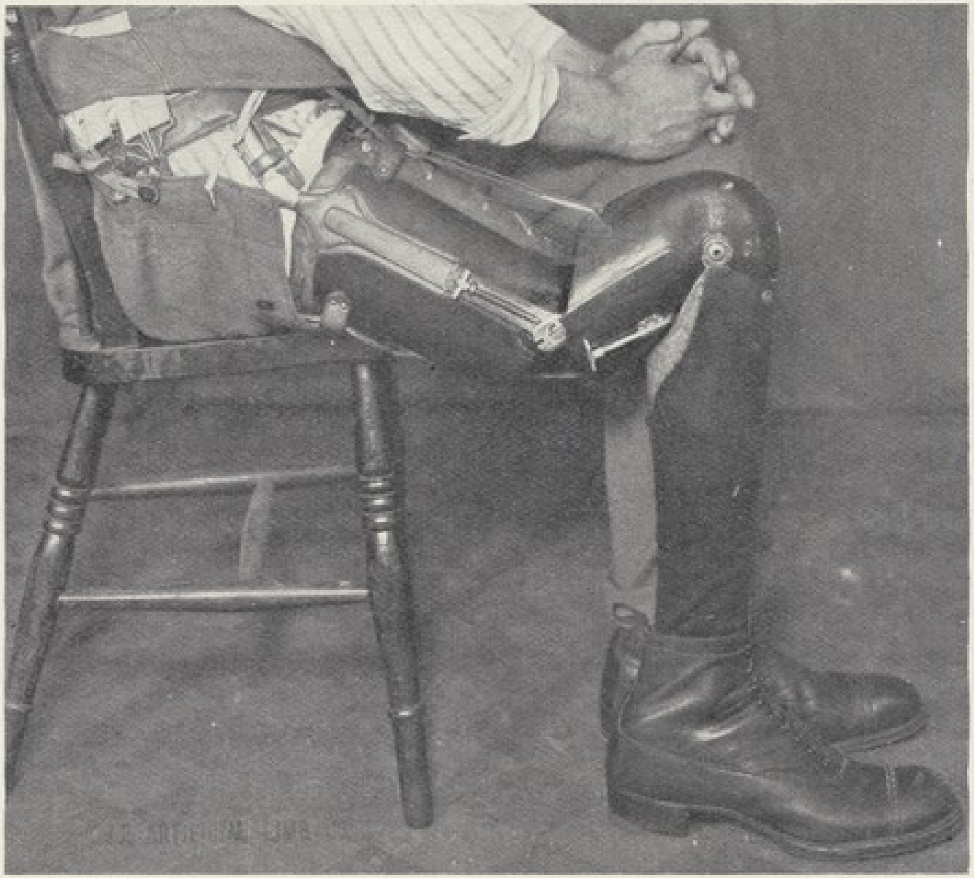


FIG. 233.—PROSTHESIS FOR AMPUTATION OF THIGH COMPLICATED BY ANKYLOSIS OF THE HIP IN ONLY PARTLY FLEXED POSITION, BY GALE AND CO.

FIG. 234.—FRONT VIEW OF PRECEDING.

[*To face p.* 252

Fig. 235.—Prosthesis for Amputation below the Knee, with a Long Stump and Ankylosis of the Knee in a Semiflexed Position, by J. F. Rowley (1919), Ltd.

FIG. 236.—LIGHT METAL LIMB WITH "CERTALMID" SOCKET FOR ANKYLOSIS OF THE HIP, MADE BY J. E. HANGER AND CO., LTD.

FIG. 237.—LIGHT METAL LIMB WITH "CERTALMID" SOCKET FOR ANKYLOSIS OF THE HIP, MADE BY J. E. HANGER AND CO., LTD.

certalmid socket fitted to a case of ankylosis of the hip, with a shorter stump which is slightly flexed and abducted, is shown in figs. 236 and 237. This limb was made by Messrs. J. E. Hanger and Co., Ltd. Ankylosis of the knee-joint causes less difficulty, particularly if the stump is short, but a long stump with a stiff knee presents more serious obstacles to fitting. These can be overcome in the manner shown in fig. 235. The stump is encased in a moulded socket, swung from the knee-joint, and the shin piece has to be cut away extensively to allow of flexion and extension of the joint. Amputation just above the condyles of the femur would have given this patient a more useful limb.

Flail joint due to paralysis of the muscles which pass over and act upon the knee-joint is a serious complication, but fortunately a rare one. It is met by adding an automatic ring catch lock to the outer knee-joint. The knee is then locked automatically as soon as the patient fully extends his knee, and is unlocked for sitting down by drawing up the ring. When such paralysis is accompanied by ankylosis of the hip, the difficulties of successful fitting are much increased.

Special limbs are sometimes required by horsemen for riding. In the case of thigh amputations the inner side of the upper two-thirds of the wooden socket is replaced by stout leather, leaving behind enough to afford a good seat to the ischial tuberosity. Or a limb with an all-leather socket may be preferred. In any case, the hard knee piece and knee-joint are not well adapted to grip the saddle, but nevertheless some amputees can ride well across country wearing the wooden socket with leather inner section.

If the amputation is below knee and the ordinary No. 8 limb is fitted, it is quite possible for the amputee to ride in it, but the inner side steel on the thigh corset and the somewhat prominent knee-joint make a comfortable grip difficult.

In the case of a long stump the No. 12 limb without side steels or knee-joints is most suitable. Even though an amputee may not be able to walk well with such a limb, he may find it quite suitable for riding, and may keep a special limb for that purpose. It might be advisable to compromise and give up the inner side steel and knee-joint only, as recommended by F. G. Ernst.

CHAPTER XX

REPAIRS TO LEG PROSTHESES

APART from wear and tear and the results of accident, alterations of the stump which destroy the correct relationship between it and the socket cause a large number of readjustments.

Shrinking of the stump is, as a rule, complete after one or at most two years' wear of a prosthesis, but this rule is by no means invariable. A fat man may lose flesh, or a muscular man may, through illness, suffer atrophy of muscles, at any period of life, and the amputation stump will take part in the changes.

The degree of incongruity between stump and socket is roughly measured by the number of stump socks which a patient finds it necessary to wear. Pensioners have returned wearing as many as twenty-four, and five or six are often found necessary. A leather lining will take the place of one or two socks, according to its thickness, but beyond this it is, generally speaking, wiser not to line or pad the socket, but to order a new one. Linings reduce the diameter equally all the way round, fill up hollows, and obliterate the accuracy of the contour of the socket, if they are of more than small thickness. This is particularly noticeable in sockets of below knee prostheses, because of the bony and unyielding nature of the stump, which necessitates accommodation of various prominences. Moreover, they add to the weight. When a patient's stump has shrunk rapidly and the process appears to be still continuing, it may be justifiable to line and pad, and defer the trouble and expense of a new socket till shrinking has stopped. Light metal sockets can be reduced in size by removing rivets and reducing the size and refixing, but this is no less troublesome or costly than a new wooden socket. The chief objection to wooden sockets is their liability to split, especially when made thin for the sake of lightness.

This tendency is prevented to a great extent by the close application and adherence of the rawhide covering or by the screw wire used by Messrs. J. E. Hanger and Co. By this method lengths of $\frac{1}{8}$ inch brass wire having a screw thread cut upon it are screwed into drill holes in the substance of the wood around the socket about 1 inch from the top. The length of each piece of wire is determined by the thickness and curvature of the socket at the site in question. The result is that a number of lengths of brass screws are imbedded, with their ends overlapping in such a manner that expansion and splitting can only occur if one or more of the wires is broken or dragged out of its bore. This method undoubtedly helps to prevent splitting, but it is doubtful whether the same result would not be obtained by riveting a narrow ring of duralumin round the outside of the top of the socket, or by the method used by C. A. Blatchford of gluing a stout linen tape round it.

A wide or long fissure necessitates a new socket, but when it is short, or runs down between two of the rivets of a knee-joint or hip-joint steel, and especially if the socket fits well, the crack may be mended by a key and an additional ring of rawhide. Well fitting and comfortable sockets, like old boots, are not to be lightly discarded, and patients are wise enough to keep them as long as possible.

CHAPTER XXI

THE RE-EDUCATION OF THE AMPUTATED

A paper introducing a discussion on this subject at the Medical Society of London on March 22, 1920.

THE physical re-education of the maimed may be attempted by means of massage and active and passive movements of what may be called a factitious nature, or by the performance of actual work, or by the two combined.

Experience has shown that, although the artificial method may be applicable earlier in the progress of a case than it is possible for actual play or work to be undertaken, yet the sooner the latter can be substituted the better the results.

The man who is set to dig or do simple woodwork can continue to do so without fatigue much longer than he can repeat dull and uninteresting movements with a Zander machine. The higher and lower nerve centres are far better occupied, and consequently redeveloped in the purposive efforts of work.

When Sir William Robertson was a non-commissioned officer he pointed out in an examination paper that a certain gymnastic exercise was absurdly impractical. In a subsequent discussion the medical officer objected to this, saying that " that exercise strengthens the muscles needed for climbing." " Why not climb, then ?" asked Robertson. This was a pertinent question, and hard to answer, unless no facilities for climbing were available. Similarly, the best way to develop stump muscles is to wear and use a prosthesis. Thereby the useful muscles will be developed, while those which, owing to loss of the segment to which they were attached, have ceased to be of use will be allowed to atrophy. To develop by ingeniously devised exercises, say, the hamstring muscles in a case of amputation in the middle of the thigh when there is neither tibia nor fibula for them to act upon would be absurd.

To obtain the best results from the natural method of training, however, the efforts of the patient must be supervised and intelligently guided by instructors, who, whenever possible, should be themselves similarly mutilated.

This has been insisted upon by Camus[1] and other French authorities on re-education, and Sir Arthur Pearson attached great importance to it in the case of the blind. He said: "The men of St. Dunstan's acquire these industries in a quarter the time that is usually supposed to be necessary to teach a blinded man the trade. The principal reason for this is found in the free employment of the blind teacher, who is not encouraged at ordinary workshops for the blind. The whole outlook of a man becomes different when he finds himself in the hands of a teacher who works under the same handicap as his own." *Mutatis mutandis*, this is exactly applicable to other disabilities.

There is no doubt that, whenever possible, the disabled man should be retrained for his old trade. It is obvious that it is best to make use of the skill and aptitude already acquired, and that it will be far easier for a man to readapt himself to it than to learn a new one.

There is a general consensus of opinion in France that the most suitable occupation for all kinds of maimed is agriculture in its widest sense. It must be remembered that 60 to 70 per cent. of the French wounded were employed upon the land before the war, and therefore a large proportion of those sent back to agriculture were resuming their former occupations. It has been found possible even to train blind men so that they may resume work among the vines, and many blind men have returned to other kinds of land work. Great efforts have been made in France to prevent the wounded agriculturists from drifting into towns.

Amar in France has devised and elaborated apparatus such as the ergometric cycle for the exact measurement and graphic record of work done by the respiratory muscles and those of the limbs in various kinds of labour, for showing fatigue, and even, as he claims, for detecting malingering.

These records cannot fail to be of physiological and pathological interest, but so far it does not appear that they have taught us more than had been learnt by empirical methods, the conclusions of which they generally confirm.

Amar's experience has been that 80 per cent. of war cripples

[1] "Physical and Occupational Re-education of the Maimed," by Dr. Jean Camus. Translation by W. T. Castle, R.N.

are capable of re-education, and 65 per cent. can be re-educated unconditionally. The remainder need specially adapted tools, machines, or workshops.

The temperament of the patient is a most important factor—almost more important than the stump.

Some men are determined to make good, and will do so. Others lack grit and perseverance, and will not try. This is true of legs as well as arms, but it is most evident in arm cases.

At Queen Mary's Convalescent Auxiliary Hospitals the first attempts at occupational training of the amputated were begun, under the direction of Mr. Dudley B. Myers, in 1915. The duration of the men's stay was too short for any complete technical training, but long enough to enable the capabilities and aptitudes of the men to be discovered, and often to lay a good foundation for subsequent education. Indeed, it has been astonishing how, in a few weeks, some men developed manual skill, which has been commonly supposed to be only attainable after years of apprenticeship. These men, when they had been fitted with their limbs, were passed on to the Polytechnic, the Cordwainers' Technical College, Clark's Commercial College, and other training centres for complete training. The subjects taught at Roehampton include commercial training, motor mechanism, metal turning and fitting, electricity, woodworking, boot making and repairing, and basket making. Training in light leather work, as also lectures and practical demonstrations on poultry farming, were given, but were abandoned for want of sufficient support. All those who have lost a right hand are taught (if they have not already learnt) to write with the left hand.

To quote Mr. Dudley Myers' report:

"An analysis of the applications received for training shows that over sixty distinct occupations were dealt with by the employment bureau and educational workshops. No fewer than 46 per cent. of the amputated at Roehampton returned to their old employment, while training or employment involving in most cases an entire change of vocation was arranged for a further 21 per cent.

"The remaining 33 per cent. were passed on to the local committees to be dealt with, being themselves unwilling to consider work or to accept training, except in the vicinity of their own homes."

The excellent work done at Roehampton and at Brighton by the Honorary Superintendent of the Employment and Training Bureau has been the model on which the Ministry of Pensions has formed its training scheme. The very greatest credit is due to Mr. Myers for the years of work which he has devoted to the interests of the amputated sailors and soldiers, with very scant recognition of his services by the Government of the country.

The value of the work done in occupational education at Lord Roberts Memorial Workshops all over the country and at Mr. Oppenheimer's diamond cutting and polishing works at Brighton is well known. But the chief function of these is vocational employment more than re-education, and a good many men working in them do not wear prostheses, because they have found jobs which can be performed without them.

The subject of re-education of the amputated naturally divides itself into two sections—(*a*) the re-education of the remaining parts of the amputated limb, so that it may again be used with or without, but most generally with, a prosthesis; and (*b*) the education of the sound limb, so that it may take the place and discharge the functions of the lost parts.

A further subdivision is concerned with the region affected—either the upper or the lower extremity—and, in the case of the upper extremities, the loss of both hands so profoundly affects the problem that such cases call for special consideration.

Temporary prostheses or provisional limbs are useful in themselves, and also as a means of training and development.

In the case of the lower extremity, they were too much neglected in this country in the earlier years of the war; and in the case of the upper extremity, they have been, and still are, very little used. This is a pity, for no doubt many a patient, before arm training schools were instituted, has been discouraged and has discarded his artificial arm because his stump muscles have atrophied from disuse, and were temporarily unequal to the tasks imposed upon them.

The re-education of the amputated may be hindered by many irremediable complications, among which are—

(*a*) Paralysis of the stump.

(*b*) Ankylosis or other defect of remaining joint or joints—*e.g.*, flail joint.

(*c*) Multiple amputations.

(*d*) Injuries and disabilities of the sound limb.

(*e*) Blindness.

As the functions of the upper extremity involve more complicated movements and co-ordination than those of the lower, it is not surprising that such complications are more difficult to deal with in the case of arm than of leg amputations.

Loss of sight, which would seem almost to forbid the use of an arm prosthesis, has not prevented St. Dunstan's from teaching arm amputees to do cabinet making, typewriting, poultry farming, etc.

In the case of leg amputees, there are, fortunately, few in which any of the above-named complications have absolutely prevented patients from walking with artificial limbs more or less well; but their re-education demands patience, perseverance, and time.

In the earlier years of the war, the number of cases was so great that the authorities, who did not properly realize the necessity of training in the use of artificial arms, did not allow any time for this purpose. The statistics as to the usefulness of arms, which were obtained by circularizing the pensioners, were so discouraging that the War Office, on the advice of the surgeons on the Advisory Council on Artificial Limbs of the Ministry of Pensions, ordered that every man who was provided with an arm prosthesis should spend at least a fortnight after receiving it in being trained in its use in an arm training school at a limb fitting hospital.

The Rev. Captain Rowlatt Maxwell, C.F., who has lost an arm a few inches below the elbow, was appointed Chief Arm Instructor to the Ministry of Pensions. The course of instruction which he advised was first given at Charterhouse Military Hospital, and afterwards at Roehampton and in the provincial centres.

It is to be remembered that, in all so-called mechanical arms, except those for cinematized stumps, the principles first employed by Baliff in 1818 are applied. That is to say, that the artificial joints are moved by means of movements of the stump and the shoulders, and even of the opposite arm. To make and co-ordinate these movements exactly, nerve centres and paths and muscles have to be adapted and developed in order to perform duties which were at first strange to them. In time, a patient who constantly uses his arm prosthesis makes the movement as automatically as those of his sound hand. He has only to will to make a certain movement of the appliance, and he does it without thinking of his shoulder, his stump, or his opposite arm, although one or some of these may do the work.

Consideration of these new neuro-muscular arrangements and of the stereognostic sense, as concerned in the use of prostheses, opens up an interesting field of study for neurologists.

A few words may be added as to the re-education of cinematized stumps. The few cases which have been admitted to hospital for the supply of arms have been treated by the application of a Thomas's arm splint, such as is used for fractures of the humerus. Indiarubber cords are attached to the distal end of the splint and to the plastic motors of the stump, and the patients are directed to exercise the muscles of the motors by pulling against the elastic resistance.

The strength and tension of the cords are easily varied.

By using this simple appliance patients gain muscular power, and the motors are lengthened and mobilized before the prosthesis is applied.

A pull of 20 pounds may be obtained from the combined biceps and brachialis motor, but this amount is probably far less than the effort of which these muscles were capable in their normal conditions; in the mutilated limb, even after considerable training, fatigue is apt to occur sooner than in the normal. One patient decided to give up the use of the cinematized stump and special prosthesis, and preferred a hand worked from the shoulders as being more powerful and causing less fatigue.

This course of arm training does not aim at teaching any trade or industry, but the patients develop the appropriate nervous control and muscular power by doing certain tasks which in themselves are interesting to them, and at the same time the nerve centres of the remaining sound limb learn to adapt themselves to new tasks, and the necessary muscles are co-ordinated and developed.

Woodwork, digging, loading and wheeling a barrow, and using a sledge-hammer, are the chief means of training.

Each man makes a number of wooden articles, and as he is allowed to take them away with him as proofs of his skill, he is interested in learning to make them well. This kind of training offers far more encouragement and hope to the men than any scheme of exercises could do. For it must not be forgotten that many of these amputees, after many operations and many months in hospital, are profoundly discouraged and sceptical as to the usefulness of an arm; but when they see what others can do, and find that they can emulate them, they regain hope and confidence.

Of course, most of the work was done with the sound hand, the artificial arm merely acting as an auxiliary. As these will be the respective functions of the two arms in after-life, this training is on the right lines.

Besides the work at the bench, those who have been fitted with workers' arms learn to use the implements for coarse work on the land before mentioned.

Although the general use of temporary peg legs was not adopted in this country till long after they had been used as a therapeutic and educational measure on the Continent, practical training in the use of permanent artificial legs was instituted from the very beginning at Roehampton.

The training begins in the limb makers' workshops, where the patient is made to try the limb in the rough by walking, at first between two parallel rails, on which he can rest his hands. At each end of these rails is a large looking-glass, in which he can see how he walks, so that he may correct errors.

These rails are supported on posts fixed to the floor. They are 2 feet 10 inches high, and each rail is 2 inches wide and rounded on the top; the distance clear between the rails is 2 feet 2 inches or 2 feet 6 inches over all. Their use enables a patient to try and walk without fear of a fall if he has the use of his hands. Errors in gait are corrected by the injunctions of the instructor, while the patient watches his reflection in the mirror.

After the limb maker has fitted and completed the limb, and is satisfied that it fits, the wearer comes into the hands of non-commissioned officers who have each lost a limb. He attends a number of walking parades, at which his errors are pointed out, and advice given for their correction. These parades are held in and out of doors, with and without the help of the rails, and include walking up and down slopes and steps, and on rough as well as smooth ground. The non-commissioned officers become very expert in instructing men how to make the best of their limbs, and in adjusting the limbs and their appendages.

After a week of this training, the patient is usually ready to pass the surgeon and be discharged. If he does not walk as well as can be expected, he may be put back for further practice and instructions.

When a man has long worn a provisional peg leg without a knee-joint, he is apt to develop a bad gait, owing to his having had to circumduct the stiff limb in bringing it forward. Practice and perseverance will in time correct this tendency.

It would be idle to deny that some men do not get on with their artificial legs from various causes, but it is gratifying to see how many men are doing well with them.

Solvitur ambulando should be the motto of those who are engaged in the re-education of the leg amputee, but in cases of very short stumps or of weakness of the muscles which control them, special exercises are often of great assistance. They are also of value in the treatment of those neurotic patients who require encouragement and persuasion to overcome their want of confidence in their own powers.

For details the reader is referred to the section on this subject in "The Handbook for the Limbless,"[1] by Miss M. Randell and Mr. G. A. Ponsonby.

[1] Published by the Disabled Society, 48, Grosvenor Square, London, W. 1.

APPENDIX I

NOTE.

In July, 1919, a committee was appointed under the chairmanship of Admiral Bacon to consider and advise the Minister of Pensions on the standardization of artificial limbs.

The recommendations of this committee were afterwards followed by the Ministry expert advisers on artificial limbs, who, after consultation with the British Limb Makers' Association, drew up the specifications for certain types of limbs, which are contained in Appendix I.

Several specimens of each type of limb have since been made and approved.

The weights of the lightest of these are as follows:

No. 1 ..	..	.. 7	pounds	7	ounces.	
,, 2 ..	..	.. 5	,,	15	,, (wooden socket).
,, 2 ..	..	.. 6	,,	8½	,, (leather socket).
,, 3 ..	..	.. 4	,,	2	,, (wooden socket).
,, 3 ..	..	.. 5	,,	15	,, (leather socket).
,, 6 ..	..	.. 5	,,	2	,, (,, ,,).
,, 8 ..	..	.. 4	,,	7	,, (wooden socket).
,, 8 ..	..	.. 5	,,	7	,, (leather socket).

SPECIFICATIONS OF ARTIFICIAL LIMBS.

Specification for Medium Carbon Steel Forgings, Artificial Limb Parts (other than the Pelvic Band).

1. **Material.**—The steel used for making these forgings is to be of British manufacture, made by an approved maker to the Ministry.

2. **Chemical Analysis.**—The steel is to contain: Sulphur, not over 0·05 per cent.; phosphorus, not over 0·05 per cent.

3. If there is any doubt as to the quality, the inspector shall have the right to select samples and have them analyzed at the Ministry's expense.

4. **Defect.**—The forgings are to be sound and free from cracks, flaws, and surface defects. They are to admit of being machined to the required dimensions without leaving witness of the black surface. Defects are not to be repaired.

5. **Tests.**—The forgings are to comply with the following tests, which are to be carried out in the presence of the inspector, and to his satisfaction:

(*a*) *Tensile Test.*—Test pieces machined cold lengthwise from the drawn down material selected must, without reheating or any other manipulation whatever, show the tensile breaking strength and minimum elongation as follows: Ultimate tensile strength, 40 to 45 tons per square inch; minimum elongation, 20 to 15 per cent.

The test piece is to be gauge length 3 inches, parallel length $3\frac{5}{8}$ inches, diameter 0·798.

(*b*) *Cold Bend Test.*—The test piece, 9 inches long and $1\frac{1}{2}$ inches square, with $\frac{1}{16}$ inch radius at the edges machined cold, must without any reheating withstand being bent cold through an angle of 90 degrees round a bar $2\frac{1}{2}$ inches diameter, and the test continued after the bar is removed by the edges being brought together without fracture. The test shall be continued after the bar is removed until the sides are parallel (British Standard Specification, Report No. 24, Specification No. 19, 1911). Should any test piece fail to fulfil the tests specified, two duplicate samples may, if the contractor wishes, be tested, and if the results obtained from both are satisfactory, the quality of the material is to be judged therefrom, and not from the original test piece which failed. If, however, either of the duplicate test pieces fail, the material represented is to be rejected.

6. **Inspection.**—The contractor is not to supply any forgings which have been previously rejected. The inspector is to have free access to the works of the contractor at all reasonable times; he is to be at liberty to inspect the manufacture at any stage, and to reject any material that does not conform to the terms of this specification.

7. **Facilities.**—The contractor is to supply the material required for testing without additional charge, and at his own cost to furnish and prepare the necessary test pieces and supply labour and appliances for such inspection and testing as may be carried out on his premises in accordance with this specification. Failing approved facilities at his own works for making the prescribed tests, the contractor is to bear the cost of carrying out the tests elsewhere.

General Information.

1. Limbs with the component steel parts standardized and built on the lines suggested in the Bacon Committee's Report shall be made according to these general specifications, but these specifications, however, shall not prevent the manufacture of any limb which, in the opinion of the Minister's advisers, constitutes an improvement as regards design, fit, material, lightness, or other qualities.

2. All metal parts which are not nickel-plated and which form component parts of the actual limb shall be painted over with an anti-corrosive varnish which is elastic.

3. Iron or steel (not copper) rivets must be used for metal parts which require to be riveted together.

4. Every limb supplied under this specification must have inscribed upon the front of the shin piece the name of the maker, the date and place of issue, and must be initialed by a responsible official of the firm before delivery.

Example:

Messrs. ________________________________

Place ________________________________

Initials and Date.

No. 1 (A).—Limb for Amputation at or just below Hip-Joint (see Fig. 238).

1. **Pelvic Socket.**—The pelvic socket shall be made of best sole bend leather, moulded to conform to the stump. It shall include one lateral half of the pelvis, and be finished so that the centre of the bottom of the saucer of the socket is lower than its inner border, as far as this is practicable.

2. **Inside Lining of Pelvic Socket.**—The pelvic socket shall be lined on the inside with best quality kid, calf, or other suitable leather—not chamois—(with or without an inner covering of best quality felt, as may be ordered by the surgeon) fitted to the material forming the pelvic socket, with a sufficient overlap to allow of the leather being securely attached to the outer circumference of the pelvic socket by best Scotch glue, or other suitable adhesive material.

3. **Outside Covering of Pelvic Socket.**—The pelvic socket shall be covered on the outside with dressed leather, metal parts being first covered with linen or other suitable material. The leather covering shall be securely fastened to the pelvic socket with best Scotch glue.

4. **Steel Bands of Pelvic Socket.**—The pelvic socket shall be embraced by two bands of steel $1\frac{1}{8}$ inches wide, No. 16 to No. 18 I.W.G., one vertical and one horizontal. The vertical one shall be of mild steel, and shall be fixed to and rest upon a plate which forms the upper arm of the inner side steel. This plate is shown in Blue Print No. S. 91. The vertical band shall be attached to the plate of the inner upper side steel by three No. 8 I.W.G. steel rivets. The horizontal band shall be of best double shear or spring steel $1\frac{1}{8}$ inches wide, No. 16 to No. 18 I.W.G.; it shall encircle the upper portion of the pelvic socket, and be prolonged to form the pelvic band. The two terminals of the vertical band shall be riveted to the horizontal band with two No. 8 I.W.G. steel rivets in each terminal. The sole bend leather of the pelvic socket shall be attached to both the steel bands by a sufficient number of No. 8 I.W.G. copper rivets to make it secure.

5. **Ventilation Holes, Pelvic Socket.**—The pelvic socket shall have

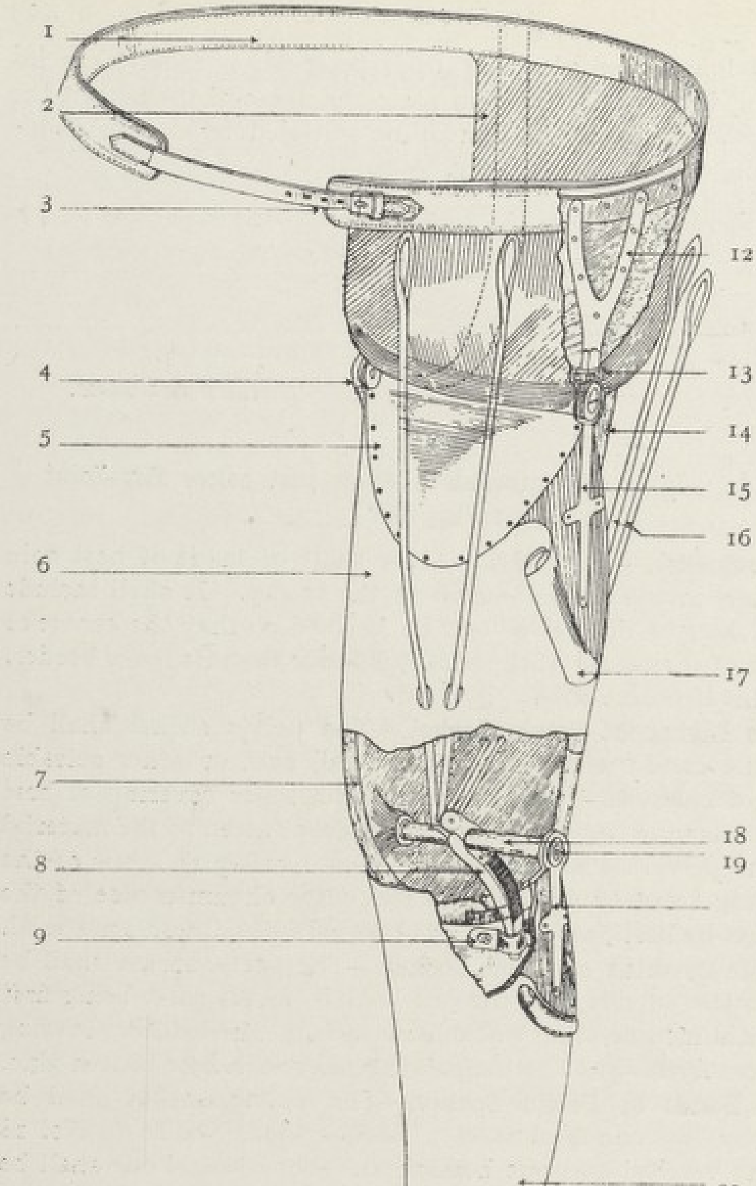


FIG. 238.—TILTING TABLE LEG, No. 1 (A).

1, Pelvic band; 2, pelvic socket; 3, leather strap; 4, inner hip-joint; 5, anterior apron; 6, thigh piece; 7, knee piece; 8, back check or knee control lever; 9, holder; 10, leather covering; 11, toe piece; 12, outer upper side steel; 13, ring catch; 14, hip extension elastic; 15, outer lower side steel; 16, knee control cords; 17, rawhide covering; 18, knee bolt (tapered); 19, knee bolt screw; 20, shin piece; 21, ankle-joint. For details of foot, see Below Knee Leg, No. 8 (H).

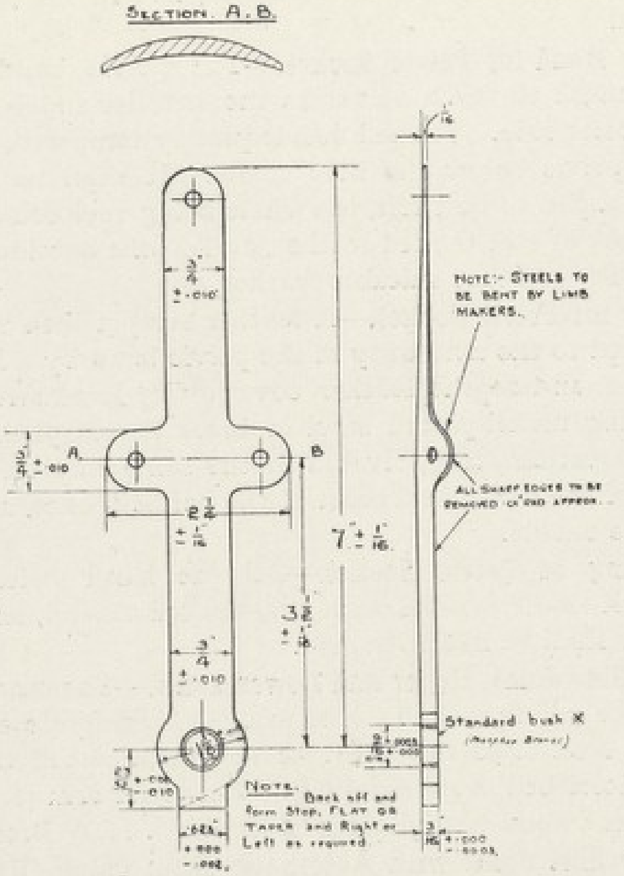


FIG. 239.—NO. I LIMB, TILTING TABLE: INNER AND OUTER LOWER STEEL. From Blue Print No. S. 90.

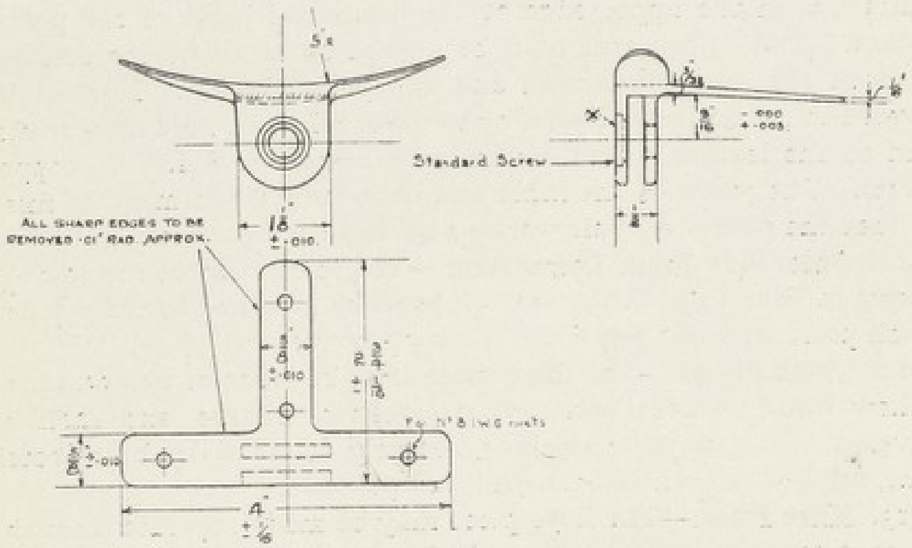


FIG. 240.—NO. I LIMB, TILTING TABLE: INNER UPPER STEEL. From Blue Print No. S. 91.

ten ventilation holes $\frac{1}{8}$ inch in diameter, five in the front and five in the back.

6. **Pelvic Band for Pelvic Socket.**—The pelvic band shall be of sufficient length to reach as far as the anterior superior iliac spine of the opposite side. It shall be adequately tempered and bevelled to fit the pelvis below the iliac crests. It shall be lined on the inside with a pad of best felt, the whole being enclosed on the inside by a covering of soft tanned leather, and on the outside by a strong bag-hide, calf, or other suitable leather.

7. **Straps for Pelvic Socket.**—A leather strap 1 inch wide shall be securely fixed to the extremity of the pelvic band by a No. 8 I.W.G. copper rivet, and to the leather covering by hand stitching. The corresponding nickel-plated steel or brass buckle shall be so fixed to a 1-inch leather strap, riveted in the same way to the anterior extremity of the horizontal band of the pelvic socket, as to provide a safe to the buckle.

8. **Stitching of Pelvic Socket.**—All the hand stitching of the leather work shall be done with best waxed thread, and all straps and buckles shall be hand stitched.

9. **Inner Side Joint, Upper and Lower Arms.**—The inner side joints which fix the pelvic socket to the wooden thigh piece are shown in Blue Prints Nos. S. 90 and S. 91. The attachment of an upper arm (S. 91) is described in paragraph 4. The lower arm (S. 90) shall be attached to the wooden thigh piece by three No. 8 I.W.G. copper rivets.

10. **Outer Side Joint with Automatic Ring Catch, Upper Arm.**—The upper arm of the outer side joint with automatic ring catch is shown in Blue Print No. S. 92. The upper extremities shall be cut off at such a level as will bring the outer hip-joint to a corresponding level with the inner hip-joint when they are affixed in contact with the upper edge of the horizontal band of the pelvic socket. This upper arm shall be curved so as to fit the contour of both the horizontal band and the pelvic socket. It shall be riveted to the horizontal band by two No. 8 I.W.G. mild steel rivets, and to the leather socket by three or more No. 8 I.W.G. copper rivets. The joints of the inner and outer side steels must be fixed so that the planes of their working surfaces are parallel.

11. **Outer Side Joint, Lower Arm.**—The lower arm of the joint is shown in Blue Print No. S. 90. It shall be attached to the wooden thigh piece by three No. 8 I.W.G. copper rivets.

12. **Thigh Pieces.**—The thigh piece shall be made of well-seasoned willow wood without detrimental cracks or shakes, and shall be covered with a suitable rawhide, securely fastened by best Scotch glue, applied hot, shellac finished and polished.

13. **Knee Piece.**—The knee piece may be made separate from the thigh piece in its entirety, in which case it shall be fixed to the thigh piece by at least four soft wood keys, diagonally placed, mortised into the two sections and securely glued.

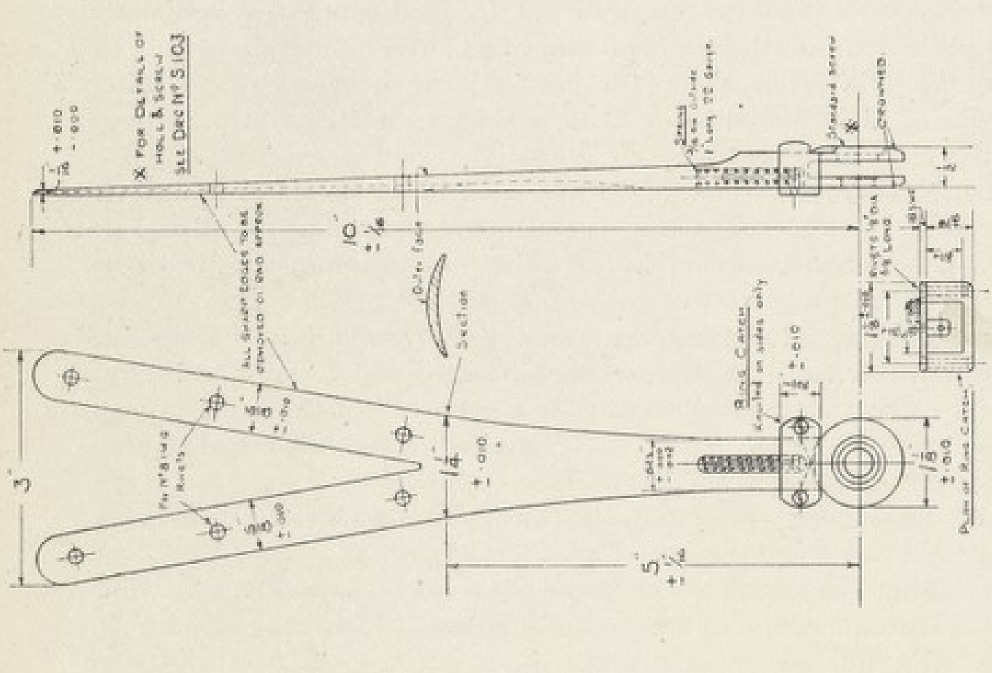


FIG. 241.—No. 1 LIMB, TILTING TABLE: OUTER UPPER STEEL. From Blue Print No. S. 92.

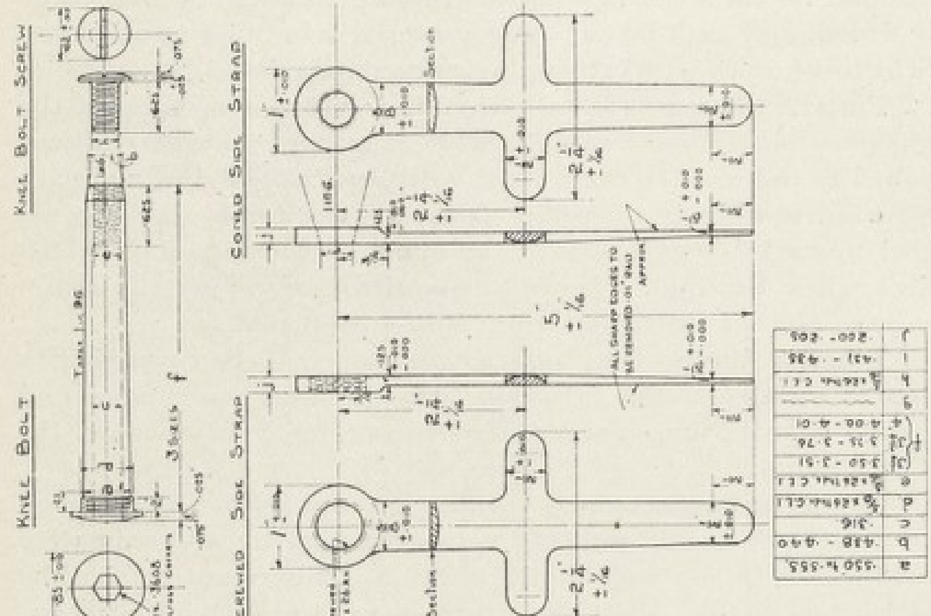


FIG. 242.—ABOVE KNEE LEG: KNEE-JOINT. From Blue Print No. S. 93.

14. **Thigh Piece to be Cut Away.**—The upper part of the thigh piece shall be cut away in front sufficiently to allow the hip to be fully flexed, and shall be cut away posteriorly in order to allow the patient to sit down with comfort when the hip is flexed.

15. **Posterior Apron.**—The whole of the posterior opening of the thigh piece shall be covered with an apron of suitable leather, attached to the wooden thigh piece with best Scotch glue, and with small counter-sunk brass wood screws. This apron shall be extended upwards so as to cover the spurs of the hip-joints which project when the hip is flexed. Opposite these spurs the apron may be reinforced with small, thin, hard steel plates.

16. **Anterior Apron.**—The anterior opening shall be covered with a piece of suitable leather, attached below by best Scotch glue, and by small counter-sunk brass screws in a similar manner to the posterior apron.

17. **Hip Extension Elastics.**—On the posterior surface of the thigh piece a piece of elastic webbing 2 inches broad by approximately 3 to 16 inches thick, bound with leather at its extremities, shall be fixed by two counter-sunk brass screws, with underlying washers, to the wooden thigh piece, and by one steel screw, No. 3 B.A., to the vertical steel band of the pelvic socket.

18. **Slot for Knee Control Lever, or Back Check.**—The knee section of the thigh piece shall be slotted with an opening 1 inch in width with a stop of suitable resilient material 1 inch wide firmly fixed (not only glued) in position. This slot shall be of sufficient extent posteriorly to allow the knee to flex to such a point as will enable the patient to kneel with comfort. The anterior margin of this slot shall be reinforced by a transverse piece of hard wood—birch, beech, or hickory—at least $1\frac{3}{4}$ inches wide, mortised into the front of the knee piece and securely glued.

19. **Knee-Joint.**—The knee-joint shall be as shown in Blue Print No. S. 93. If prescribed, a knee control, according to Blue Print No. S. 95, shall be fitted. If a knee control is not supplied, then paragraphs 24 and 25 will not apply.

20. **Bushing of Knee-Joint.**—The bushing shall be of the best sole, butt, or bend leather, securely lapped and glued, and brought to its correct internal diameter by a mandrel (of the same taper as defined in Blue Print No. S. 93), being inserted and worked in under pressure with tallow and graphite.

21. **Knee Lock.**—The knee lock, when required, shall be as shown in Blue Print No. S. 94.

22. **Shin Piece.**—The shin piece shall be of well-seasoned willow wood without detrimental cracks or shakes. Into this wooden shin piece the side straps of the knee-joint (Blue Print No. S. 93) shall be accurately recessed and attached by three No. 8 I.W.G. copper rivets (two rivets in the cross and one near the extremity of the lower end of the steel), the heads of which shall be flush. The shin

piece shall be covered with rawhide, as described in paragraph 12. The rawhide shall completely cover the side straps.

23. **Knee Control.**—The knee control lever, or back check, shall be inserted into a bearing of grease-tanned hide at its anchorage point in the back of the shin piece. The holder of the knee control shall be attached to the shin piece by two flat-headed slotted steel bolts, No. 3 B.A. (Blue Print No. S. 95). If an elastic knee control is required, two pieces of elastic webbing 1 inch in width shall be

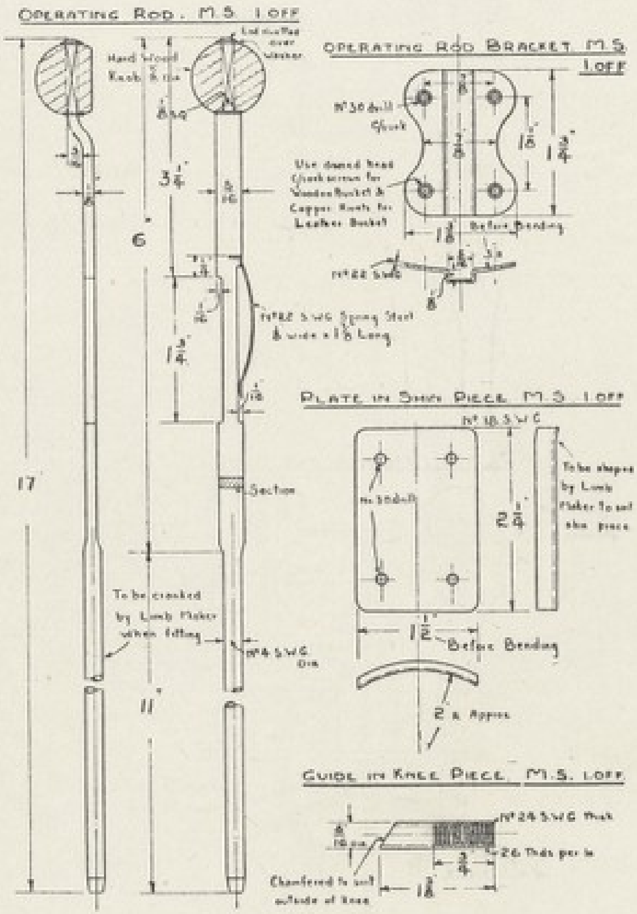


FIG. 243.—KNEE LOCK.
From Blue Print No. S. 94.

fixed to the front of the wooden thigh piece, and shall extend to the shin piece and be attached thereto by three counter-sunk brass screws with washers. The extremities of the elastic at the points of fixation shall be bound with leather for a length of 1 inch. If a shoulder knee control is required, the guides and control cords shall be as described in paragraphs 24 and 25.

24. **Control Cord Guides.**—The guides for the control cords shall be of bridle or other suitable leather $\frac{7}{8}$ inch in width, and securely fastened to the socket by $\frac{1}{2}$ inch No. 6 wood screws counter-sunk flush with the leather.

25. **Knee Control Cords.**—The knee control cords shall be of best raw or grease-tanned hide 44 inches in length and of a suitable diameter to fit the rollers, each end to be securely stitched, split or riveted to form a loop for suspension.

26. **Ankle Base.**—A block of suitable hard wood—birch, beech, or hickory—close-grained and well seasoned to take the upper portion of the ankle-joint, shall be fixed to the lower extremity of

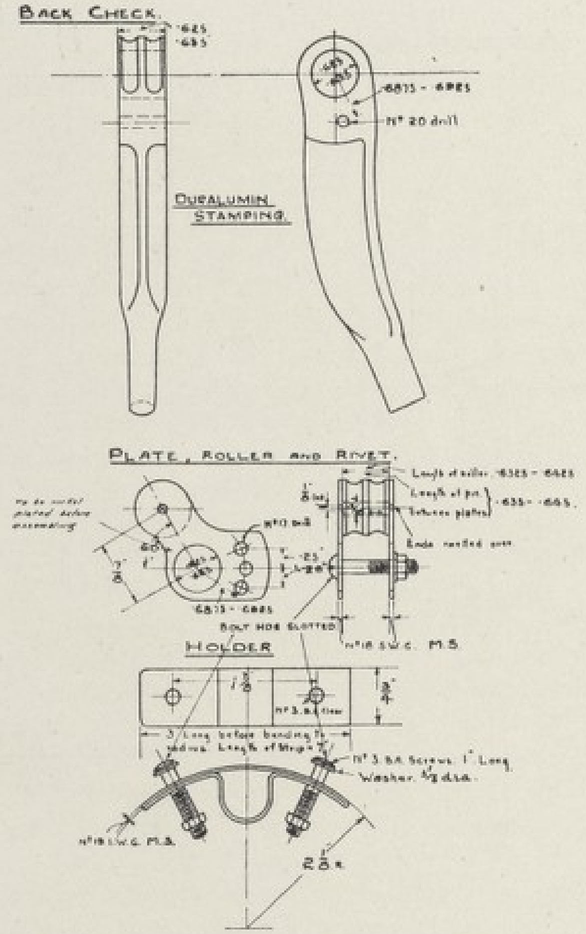


FIG. 244.—BACK CHECK FOR ABOVE KNEE LEGS NOS. 1, 2, AND 3. From Blue Print No. S. 95.

the shin piece by best Scotch glue, and, in addition, by two steel wood screws. This hard wood block shall be extended in front in the form of a beak or tongue so as to compress the front rubber.

27. **Strength of Thigh and Shin Piece.**—Both the thigh and shin piece shall be of sufficient strength to allow of an ample margin of safety for the individual patient for whom the limb is made, according to his weight, height, and the nature of his occupation.

28. **Foot.**—The foot shall be fashioned out of a piece of well-seasoned willow wood without detrimental cracks or shakes, of a suitable shape and size to fit the patient's boot, either solid or hollowed out in the instep. If the latter, care must be taken that it is not unduly weak. A suitable willow wood toe piece shall also be provided.

29. **Ankle-Joint.**—Alternative patterns of ankle-joints are shown in Blue Print No. S. 96 and Blue Print No. S. 97.*

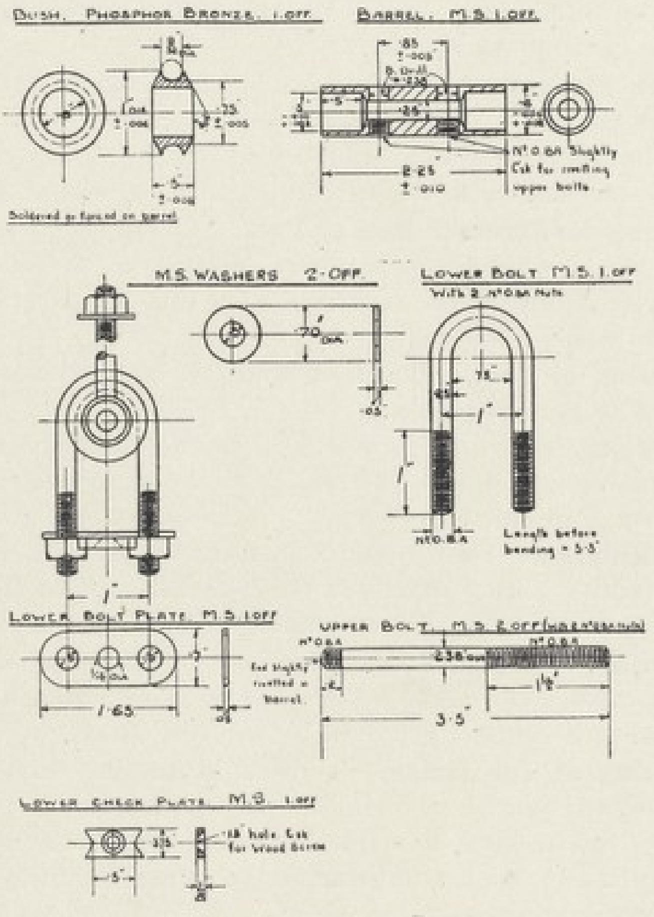


FIG. 245.—ANKLE-JOINT.
From Blue Print No. S. 96.

30. **Bushing of Ankle-Joint** (Blue Print No. S. 96).—If ankle-joint No. S. 96 is used, the bushing to take the ankle-joint shall be of best sole, butt, or bend leather or suitable rawhide accurately fitted and glued into position and treated with tallow and graphite, care being taken that the recess to take the phosphor-bronze collar is accurately fitted so as to obviate any lateral movement taking place in the joint.

* The alternative pattern of ankle-joint S. 97 is not now issued. The only standard pattern is that shown in fig. 245.

31. **Heel Rubber.**—In the heel of the foot a tapered hole shall be cut 1 inch in diameter at the base, which may be extended through the heel (or alternatively some wood may be left) to take a piece of cylindrical commercial rubber of approved quality of 1 inch diameter, sufficient space being allowed for the expansion of the rubber when weight is put upon it.

32. **Front Rubber.**—In the front or arch of the foot a recess shall be made to take a suitable plunger of commercial rubber of approved quality, which shall be oblong with a rounded upper surface, the recess to be sufficiently large to allow of compression without pinching or cutting the rubber.

33. **Check Plates.**—Check plates of metal shall be fitted to keep the nuts of the bolts of the ankle-joint from turning, such check plates to be securely fixed, each by a brass wood screw. These check plates are shown in Blue Prints Nos. S. 96 and S. 97.

34. **Opening for Access to Nuts on Foot.**—Sufficient opening shall be allowed in the wood, leather, and felt covering of the under portion of the foot to allow of the insertion of a box spanner, so that the nuts may be easily removed.

35. **Covering of Foot.**—The foot shall be covered with rawhide, as described in paragraph 12.

36. **Toe-Joint.**—The toe-joint shall be made of best balata or leather, securely glued and fixed by brass wood screws to the under portion of the foot and toe piece.

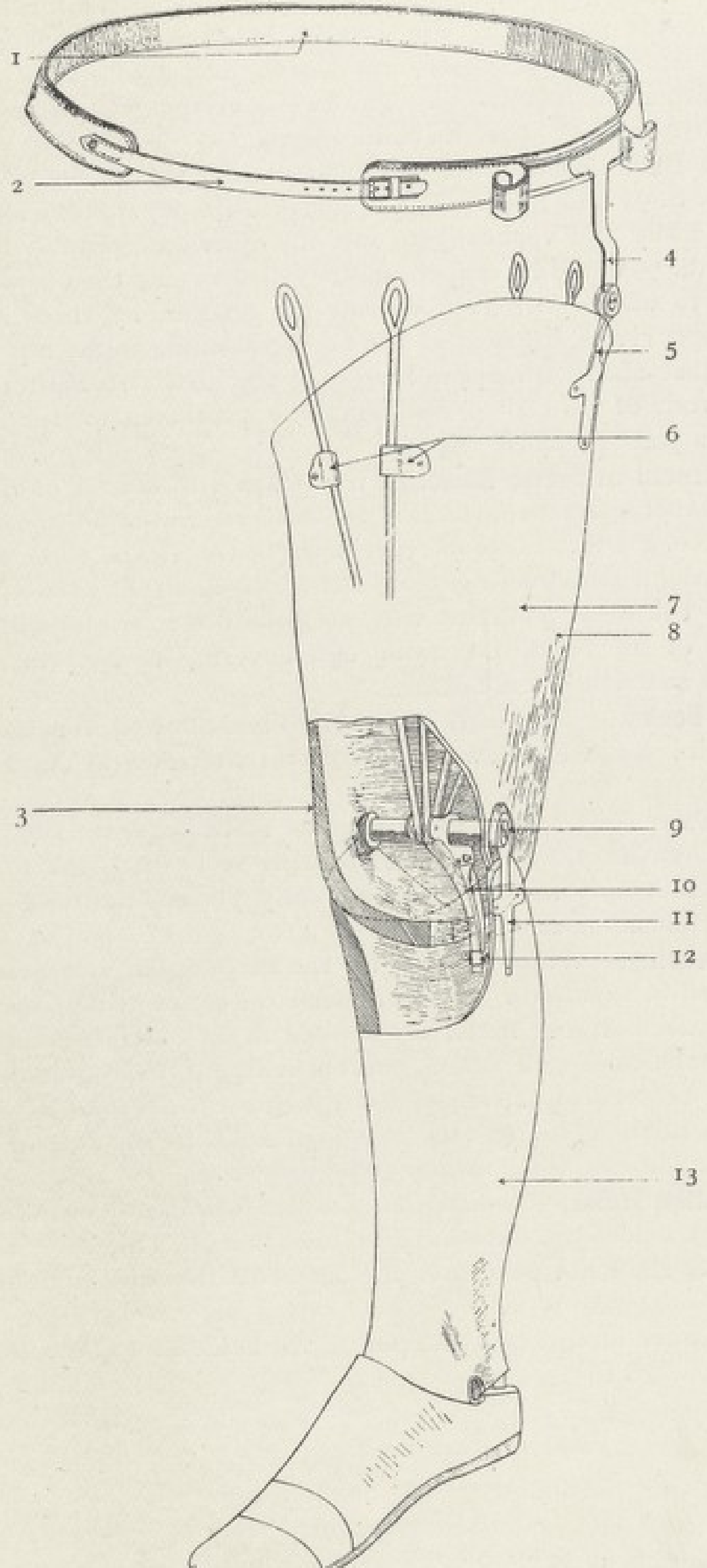
37. **Toe Rubbers.**—Two cylindrical commercial rubber buffers of approved quality ½ inch diameter shall be inserted in the toe-joint to give the necessary compression and spring.

38. **Covering of Sole of Foot.**—The sole of the foot shall be well padded with felt, over which a covering of suitable leather, with its edges skived to a knife edge, shall be securely glued.

39. **Covering of Toe Hinge.**—A piece of similar suitable leather shall be provided for the covering of the toe hinge. To add further security to this covering, five small counter-sunk brass wood screws (not tacks) shall be fixed along each edge of the covering on the toe piece and on the foot.

No. 2 (B).—Limb for Amputation in Upper Part of Thigh with Pelvic Band (Wooden Socket) (see Fig. 246).

1. **Pelvic Band.**—The pelvic band shall be of best spring or double shear steel 1⅛ inches in width, Nos. 16 to 18 I.W.G., as prescribed by the surgeon, adequately tempered and bevelled to fit the pelvis below the iliac crests. It shall encircle the back of the pelvis and extend in front beyond each anterior superior iliac spine. This band shall have attached to it the upper male arm of the pelvic band joint (see Blue Print No. S. 98) by three No. 8 I.W.G. mild steel rivets, care being taken to see that the rivets are of sufficient



1, Pelvic band; 2, leather strap; 3, knee piece; 4, upper steel of P.B. joint; 5, lower steel of P.B. joint; 6, control cord guides; 7, thigh socket; 8, rawhide covering; 9, knee-joint; 10, knee control lever; 11, side strap; 12, holder; 13, shin piece. For details of ankle base and foot, see Below Knee Leg, No. 8 (H).

FIG. 246.—ABOVE KNEE LEG, NO. 2 (B): WOODEN SOCKET.

length to form a good head. The pelvic band shall be lined with best felt on the inside, the whole being enclosed in a covering of soft tanned leather on the inside, and a strong bag-hide, calf, or other suitable leather on the outside. The two coverings of leather shall be firmly stitched with best machine thread.

2. **Pelvic Band Joint.**—The pelvic band joint is shown in Blue Prints Nos. S. 98 and S. 99. The upper arm (S. 98) shall be shaped (or set) laterally and vertically to suit the individual patient. The lower arm (S. 99) shall be shaped and bevelled to suit the contour of the socket to which it is fixed outside the rawhide by three No. 8 I.W.G. copper rivets. The steel joint corresponding to the hip shall be placed just above the upper border of the great trochanter and rather in front of its centre, and shall be protected on the inner surface by a pad of chrome leather.

3. **Adjustment of Pelvic Band.**—Two straps 1 inch wide of strong suitable leather shall be attached to the extremities of the steel band by a No. 8 I.W.G. copper rivet in each, the straps to be hand stitched through the covering, one of them to be fitted with a steel buckle and the other punched with suitable holes to allow of the adjustment of the band, the lining and covering to be prolonged to provide a safe under the buckle.

4. **Thigh Socket.**—The thigh socket shall be hollowed from a solid piece of well-seasoned willow wood without detrimental cracks or shakes.

5. **Knee Piece.**—The knee piece may be made separate from the socket in its entirety, in which case it shall be fixed to the socket by at least four soft wood keys, diagonally placed, mortised into the two sections and securely glued.

6. **End Bearing.**—When ordered by the surgeon, an end bearing shall be fitted in this limb. It shall consist of a pad of best sponge rubber or other suitable material enclosed in an outer covering of chrome, tanned sheep, or other suitable leather, the edges of the covering to be securely stitched and not glued. It shall be supported by a rawhide thong, laced through holes in the side of the socket below the end of the stump.

7. **Ventilation Holes.**—Ventilation holes shall be cut on either side of the socket below the extremity of the stump. The lower ends of these holes shall not be nearer the centre of the knee-joint than 2 inches.

The remainder of this specification is the same as for the No. 1 Limb, Sections 18 to 39.

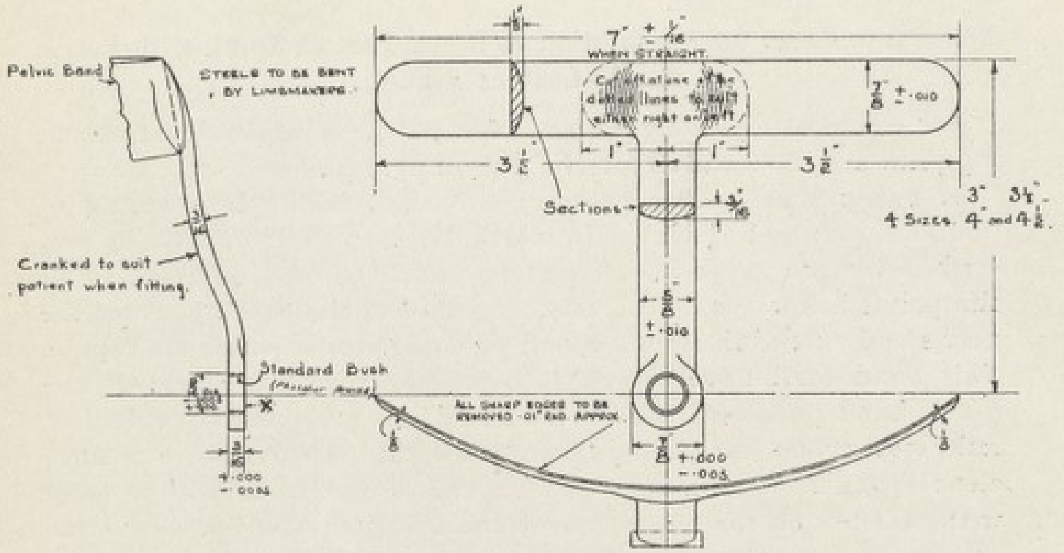


FIG 247.—PELVIC BANID: UPPER STEEL.
From Blue Print No. S. 98.

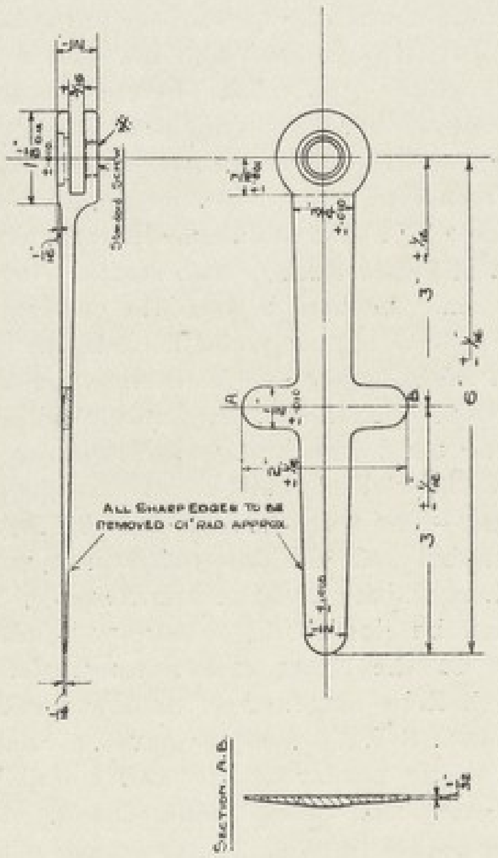


FIG. 248.—KNEE-JOINT, LOWER STEEL, FOR BELOW KNEE, THROUGH KNEE, AND KNEELING LEGS.
From Blue Print No. S. 99.

No. 2 (C).—Limb for Amputation in Upper Part of Thigh with Pelvic Band (Leather Socket).

For illustration see fig. 249 of No. 3 (E). The pelvic band and hip-joint are the same as for No. 2 B in fig. 246.

1. **Pelvic Band.**—The pelvic band shall be of best spring or double shear steel 1⅛ inches in width, Nos. 16 to 18 I.W.G., as prescribed by the surgeon, adequately tempered and bevelled to fit the pelvis below the iliac crests. It shall encircle the back of the pelvis and extend in front beyond each anterior superior iliac spine. This band shall have attached to it the upper male arm of the pelvic band joint (see Blue Print No. S. 98) by three No. 8 I.W.G. mild steel rivets, care being taken to see that the rivets are of sufficient length to form a good head. The pelvic band shall be lined with best felt on the inside, the whole being enclosed in a covering of soft tanned leather on the inside, and a strong bag-hide, calf, or other suitable leather on the outside. The two coverings of leather shall be firmly stitched with best machine thread.

2. **Pelvic Band Joint.**—The pelvic band joint is shown in Blue Prints Nos. S. 98 and S. 99. The upper arm (S. 98) shall be shaped (or set) laterally and vertically to suit the individual patient. The lower arm (S. 99) shall be shaped and bevelled to suit the contour of the socket to which it is fixed outside the rawhide by three No. 8 I.W.G. copper rivets. The steel joint corresponding to the hip shall be placed just above the upper border of the great trochanter and rather in front of its centre, and shall be protected on the inner surface by a pad of chrome leather.

3. **Adjustment of Pelvic Band.**—Two straps 1 inch wide of strong suitable leather shall be attached to the extremities of the steel band by a No. 8 I.W.G. copper rivet in each, the straps to be hand stitched through the covering, one of them to be fitted with a steel buckle and the other punched with suitable holes to allow of the adjustment of the band, the lining and covering to be prolonged to provide a safe under the buckle.

4. **Thigh Socket.**—The thigh socket shall be of best sole, butt, or bend leather moulded to fit the patient's stump, with a lap in front of at least 1 inch in width skived to a knife edge, or the lower part of the socket may be closed and a V-shaped piece cut out above for adjustment. In the latter case a tongue of bridle or other suitable leather shall be attached at its lower end to the wooden knee piece by a No. 8 I.W.G. copper rivet. The tongue shall be turned over the upper border of the socket, and be punched and eyeleted for the insertion of the lacing thong. The edges of the tongue within the socket to be skived to a knife edge.

5. **Lacing Pieces.**—When the edges of the socket are made to overlap, a lacing piece on each side of the socket of best stout upper or other suitable leather 1¼ inches to 1½ inches in width shall be

hand sewn with best waxed thread (for a distance of 8 inches or more to suit individual patients) down the socket, and punched to allow of the insertion of brass, nickelled, or other suitable eyelets (with holes not less than ¼ inch in diameter) clenched on the inside surface and flush both inside and outside with the leather. The socket shall be laced with a grease-tanned leather thong. When the socket is closed below and a V-shaped piece cut out, the edges of this gap shall themselves be punched and fitted with eyelets in the manner described above.

6. **Knee Piece.**—The knee piece or lower portion of the socket shall be made of well-seasoned willow wood without detrimental cracks or shakes. It shall be overlapped by the leather socket at least 1 inch in depth, thereby forming a butt and lap joint. This butt joint shall be securely glued, and care taken that the inside of the wooden knee piece is skived down to a knife edge so that the inside of the socket presents a perfectly even surface as far as practicable.

7. **End Bearing.**—When ordered by the surgeon, an end bearing shall be fitted in this limb. It shall consist of a pad of best sponge rubber or other suitable material enclosed in an outer covering of chrome, tanned sheep, or other suitable leather, the edges of the covering to be securely stitched and not glued. It shall be supported by a rawhide thong laced through holes in the side of the socket below the end of the stump.

8. **Strengthening Pieces.**—Four strengthening pieces of No. 20 I.W.G. hardened steel ⅝ inch wide shall extend from a point about 1 inch from the upper edge of the leather socket to overlap the wooden knee piece for a length of at least 1 inch, these strengthening pieces to be recessed into the wood until they are flush, and attached by a sufficient number of No. 8 I.W.G. copper rivets well countersunk, flush, and not in the same grain, to the leather socket and wooden knee piece respectively. The strengthening pieces shall be placed in such a position that they do not interfere with the lacing pieces or the compression of the socket.

9. **Lining of Socket.**—The inside of the socket may be lined with chrome, doe, soft tanned sheep, or other suitable leather (not chamois) over a layer of felt if considered advisable. The upper edge of this lining should be left long enough to overlap the top of the socket and be securely fastened thereto. The lower edge of this lining shall also be securely glued to the interior of the socket. When the V-shaped type is made, the inside lining shall be long enough to form a facing 1½ inches in width on each side of the gap, and shall be securely fastened to the outside of the socket.

10. **Ventilation Holes.**—Ventilation holes shall be cut on either side of the socket below the extremity of the stump. The lower ends of these holes shall not be nearer the centre of the knee-joint than 2 inches.

The remainder of this specification is the same as for the No. 1 Limb, Sections 18 to 39.

No. 3 (D).—Limb for Amputation in Lower Part of Thigh without Pelvic Band (Wooden Socket).

The specification for this limb is the same as that for the No. 2 Limb (Wooden Socket), omitting Sections 1 to 3.

No. 3 (E).—Limb for Amputation in Lower Part of Thigh without Pelvic Band (Leather Socket) (see Fig. 249).

The specification for this limb is the same as that for the No. 2 Limb (Leather Socket) (D), omitting Sections 1 to 3.

No. 6 (F).—Limb for Amputation Through or Just Above the Knee-Joint (see Fig. 250).

1. **Thigh Socket.**—The thigh socket shall be of best sole, butt, or bend leather, blocked to fit the patient's stump, with an opening in front of at least 1 inch in width, with a suitable tongue or lap, grain of leather inwards, and covered with rawhide, shellac finished and polished.

2. **Lacing Pieces.**—When the edges of the socket are made to overlap, a lacing piece on each side of the socket of best stout upper or other suitable leather 1¼ inches to 1½ inches in width shall be hand sewn with best waxed thread the whole of the way down the socket, and punched to allow of the insertion of brass, nickelled, or other suitable eyelets (with holes not less than ¼ inch in diameter), clenched on the inside flush with the leather. The socket shall be laced with a grease-tanned thong. When a tongue is fitted, the edges of the socket shall themselves be punched and fitted with eyelets in the manner described above.

3. **End Bearing Pad.**—Unless otherwise ordered, the bottom of the socket shall be fitted with an end bearing pad of best sponge rubber or other suitable material, enclosed in an outer covering of chrome, tanned sheep, or other suitable leather, the edges of the covering to be securely stitched, and not glued.

4. **Extension Elastic.**—A forked extension piece, consisting of two leather straps cut out of one piece, shall be extended a sufficient distance down the shin piece, so that, when the elastic referred to later is fully extended, the friction or wear on the knee part is taken on the leather strap and not on the elastic webbing. To the lower extremity of this forked strap a piece of elastic webbing 2 inches in width shall be securely hand stitched to extend down the front portion of the shin piece to a point just above the top of the boot. The elastic webbing shall be bound on its lower extremity with a tab of leather securely hand stitched, the leather tab being attached to the wooden shin piece by three bevel-headed brass wood screws with underlying washers fixed in a triangular position

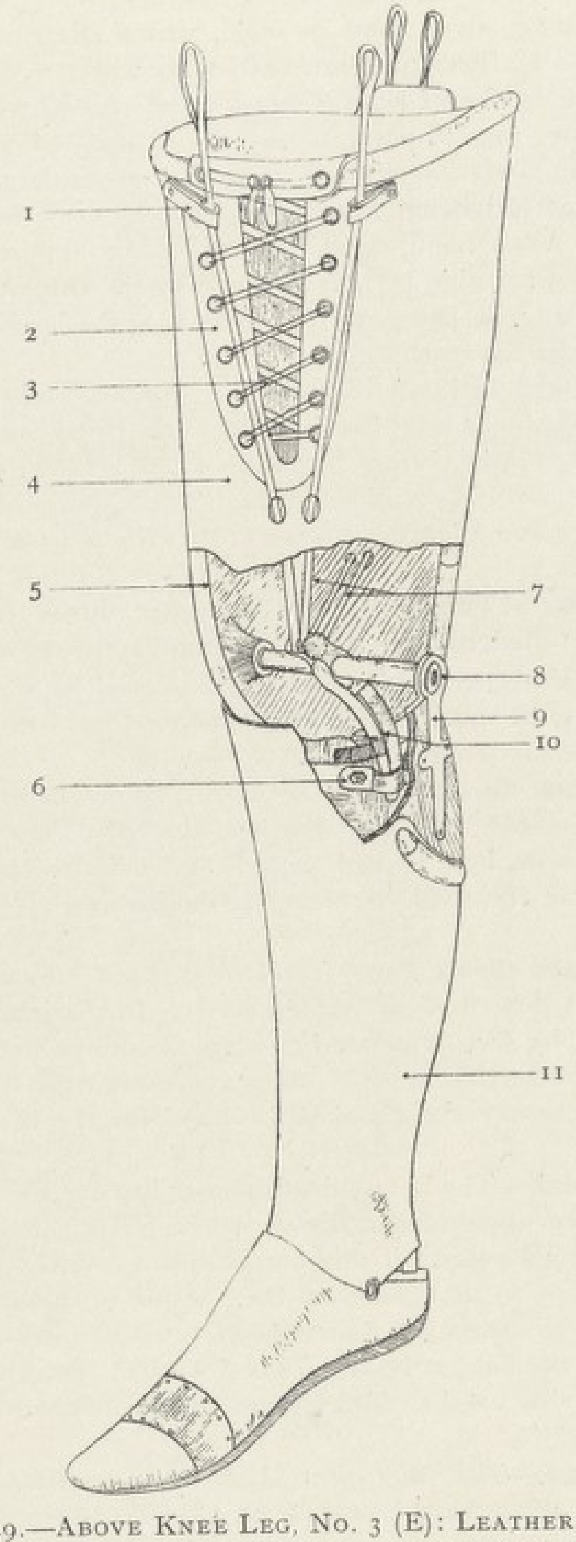


FIG. 249.—ABOVE KNEE LEG, NO. 3 (E): LEATHER SOCKET.

1, Control cord guide; 2, lacing piece; 3, grease-tanned leather thong; 4, leather socket; 5, knee piece; 6, holder; 7, control cords; 8, knee-joint; 9, side strap; 10, knee control lever; 11, shin piece. For details of ankle base and foot, see Below Knee Leg, No. 8 (H).

on the edges of the aforementioned leather tab. Alternatively a bifurcated leather strap may be used, which shall be cut out of a solid piece of leather, and attached near the top of the front of the shin piece by bevel-headed brass wood screws with underlying washers. The upper portion of this bifurcated strap shall be attached through elastic extensions to the suspenders.

5. **Guides for Extension Elastic.**—In the case of the last referred to bifurcated strap being used, the guides through which the strap runs shall be of suitable leather stitched to the thigh socket, as also shall be the strap on the posterior surface of the socket to take the other end of the harness.

6. **Elastic Back Lift.**—A leather tab 2 inches wide by 3½ inches long shall be attached to the back of the thigh socket by three No. 8 I.W.G. copper rivets, to which shall be securely stitched a piece of elastic webbing 2 inches wide. The upper end of the elastic webbing shall have a leather tab securely stitched for connection to braces.

7. **Upper Edge of Thigh Socket.**—The upper edge of the thigh socket shall be well rolled over to take bearing on the tuberosity of the ischium, and, if necessary, it shall be reinforced by strips of leather firmly glued on to the socket and skived on their lower edges so as to give a perfectly smooth finish.

8. **Upper Back Check Tab.**—The upper back check tab shall be of best bridle or other suitable leather, riveted to the thigh socket, or hand sewn with best waxed thread, and fitted with two or more eyelets to allow the rawhide thong to be inserted, as described in paragraph 2.

9. **Lower Back Check Tab.**—The lower back check tab shall be similar to that described in paragraph 8. It shall be attached to the shin piece by two or more brass wood screws with underlying washers, and be further secured along its lower edge by small brass pins. The necessary eyelets shall be fixed for the insertion of the rawhide thong.

10. **Knee-Joint.**—The knee-joint is shown in Blue Prints Nos. S. 99 and S. 100. The upper arm of the joint (No. S. 100) shall be attached to the socket by a sufficient number of No. 8 I.W.G. copper rivets, the riveted heads to be flush with the outside of the steel arm, and the rivet holes in the steel joints to be well counter-sunk to give a firm hold to the copper rivets. The joints of the inner and outer side steels must be fixed so that the planes of their working surfaces are parallel.

11. **Shin Piece.**—The shin piece shall be of well-seasoned willow wood without detrimental cracks or shakes. Into this wooden shin piece the lower side straps of the knee-joint (Blue Print No. S. 99) shall be accurately recessed and attached by three No. 8 I.W.G. copper rivets (two rivets in the cross and one near the extremity of the lower end of the steel), the heads of which shall be flush. The

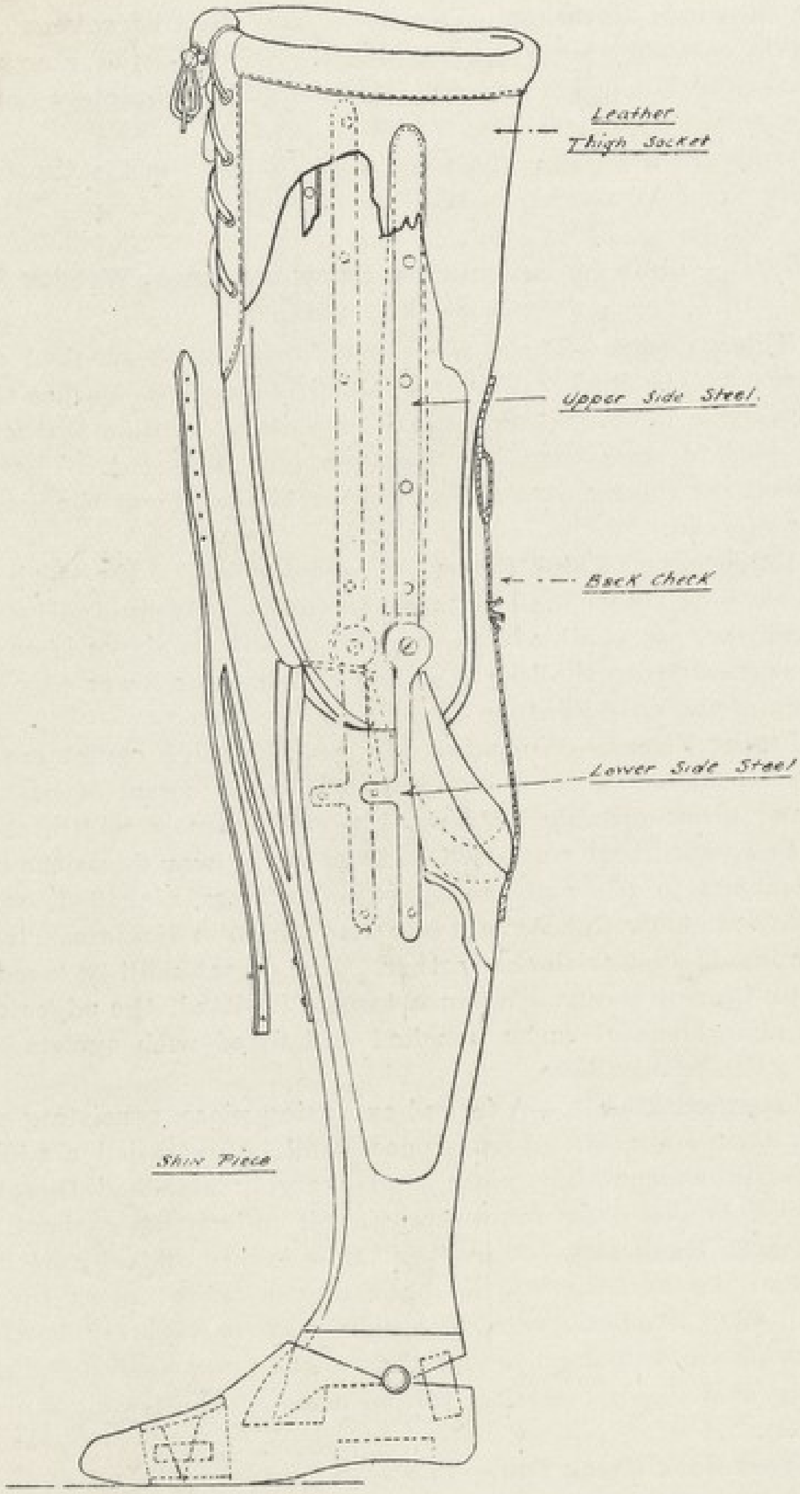


FIG. 250.—THROUGH KNEE LEG, NO. 6 (F).
For details of ankle base and foot, see Below Knee Leg, No. 8 (H).

top of the shin piece shall be cut away at the back, enough to enable the wearer to kneel with comfort.

12. **Rawhide Covering.**—The shin piece shall be covered with a suitable rawhide, securely fastened by best Scotch glue applied hot, shellac finished and polished, and shall completely cover the side straps.

The specification for the remainder of this limb is the same as for the No. 1 Limb (A), Sections 26 to 39.

No. 8 (G).—Limb for Amputation Below the Knee (Wooden Socket) (see Fig. 252).

1. **Thigh Corset.**—The thigh corset shall be of blocked or soft leather. In the former case, best sole, butt, or bend leather shall be used; in the latter, chrome tanned or other suitable leather lined with doeskin, sheep, or soft Helvetia (not chamois). The height to which the thigh corset extends upwards shall be at the discretion of the surgeon.

2. **Extension of Thigh Corset.**—The extension of the thigh corset down the side steels shall be made to suit each individual patient, and the surgeon shall advise whether or not an above knee transverse leather strap shall be attached between the lower edge of the corset and the knee-joint.

3. **Lacing Pieces.**—When the edges of the thigh corset are made to overlap, a lacing piece on each side of the corset of best stout upper or other suitable leather, $1\frac{1}{4}$ to $1\frac{1}{2}$ inches in width, shall be hand sewn with best waxed thread the whole way down the corset, and punched to allow of the insertion of brass, nickelled, or other suitable eyelets (with holes not less than $\frac{1}{4}$ inch in diameter) clenched on the inside flush with the leather. The corset shall be laced with a grease-tanned thong. When a tongue is fitted, the edges of the corset shall themselves be punched and fitted with eyelets in the manner described above.

4. **Extension Elastic.**—A forked extension piece, consisting of two leather straps cut out of one piece, shall be extended a sufficient distance down the shin piece, and securely attached thereto by two bevel-headed brass wood screws with underlying washers.

5. **Elastic Back Lift.**—A leather tab 2 inches wide by $3\frac{1}{2}$ inches long shall be attached to the back of the thigh corset by three No. 8 I.W.G. copper rivets, to which shall be securely stitched a piece of elastic webbing 2 inches wide. The upper end of the elastic webbing shall have a leather tab securely stitched for connection to braces.

6. **Upper Back Check Tab.**—The upper back check tab shall be of best bridle or other suitable leather, riveted to the thigh socket or hand sewn with best waxed thread, and fitted with two or more eyelets to allow the rawhide thong to be inserted as described in paragraph 3.

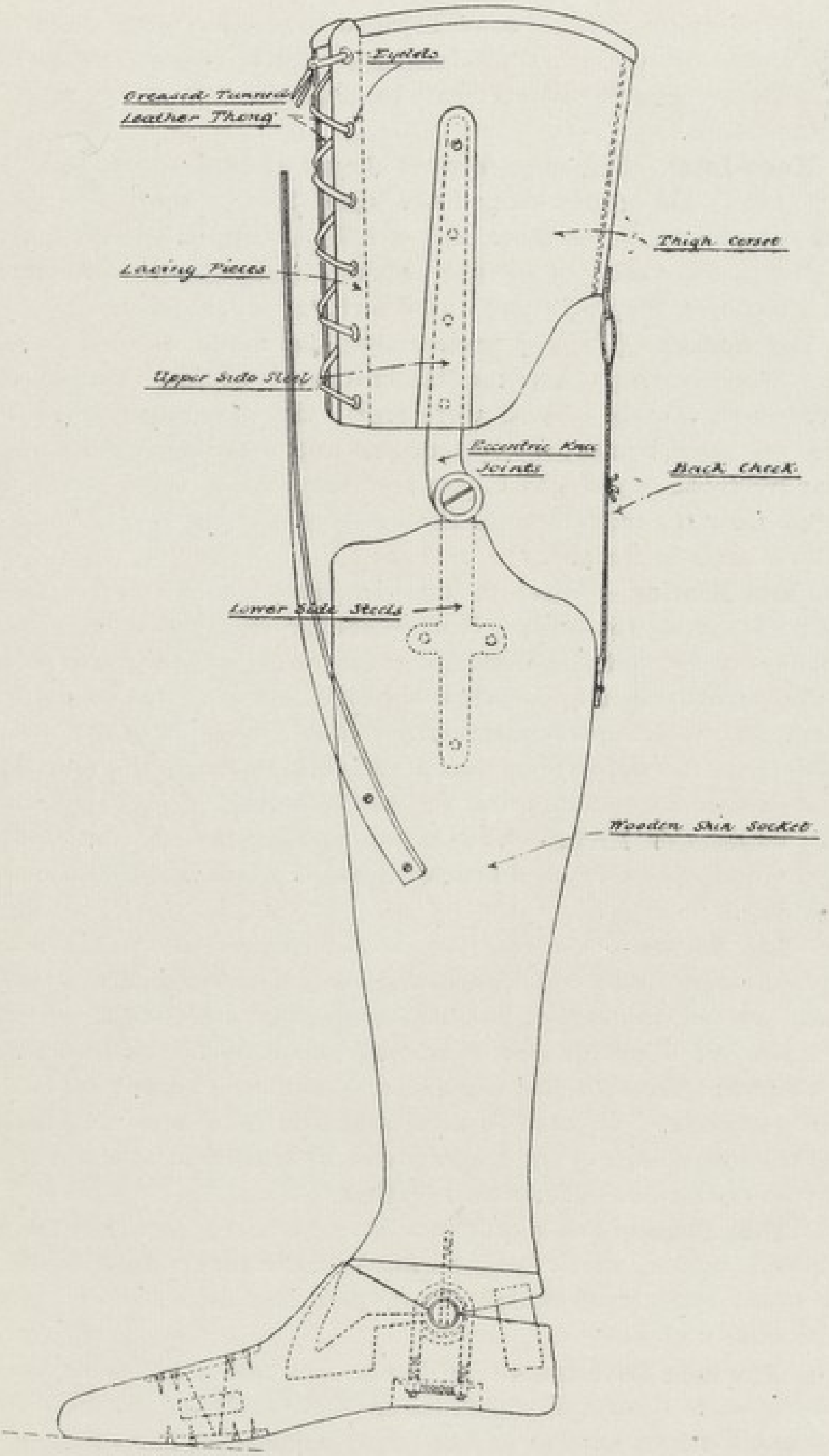


FIG. 251.—BELOW KNEE LEG, NO. 8 (G): WOODEN SOCKET.
For details of ankle base and foot, see Below Knee Leg, No. 8 (H).

7. **Lower Back Check Tab.**—The lower back check tab shall be similar to that described in paragraph 6. It shall be attached to the shin piece by two or more brass wood screws with underlying washers, and be further secured along its lower edge by small brass pins. The necessary eyelets shall be fixed for the insertion of the rawhide thong.

8. **Knee-Joint.**—The knee-joint is shown in Blue Prints Nos. S. 99 and S. 101. The upper arm of the joint (S. 101) shall be attached to the thigh corset by three No. 8 I.W.G. copper rivets, and protected with a covering of suitable leather, which shall be of sufficient length to cover the inner and outer surfaces of the joints.

9. **Leg Socket.**—The leg socket shall be made of well-seasoned willow wood without detrimental cracks or shakes, shaped to fit the patient's stump. The lower arm of the knee-joint (Blue Print No. S. 99) shall be accurately recessed and attached to the wooden socket by three No. 8 I.W.G. copper rivets (two rivets in the cross and one near the extremity of the lower end of the steel), the heads of which shall be flush.

10. **End Bearing.**—When ordered by the surgeon, an end bearing shall be fitted in this limb. It shall consist of a pad of best sponge rubber or other suitable material enclosed in an outer covering of chrome, tanned sheep, or other suitable leather, the edges of the covering to be securely stitched and not glued. It shall be supported by a rawhide thong laced through holes in the side of the socket or shin piece below the end of the stump.

11. **Ventilation Holes.**—Ventilation holes 1 inch in diameter shall be provided on either side of the shin piece below the extremity of the stump.

12. **Slip Socket.**—For this leg, a slip socket of leather may be supplied when ordered by the surgeon. It shall accurately fit the stump and be enclosed in the upper end of the leg socket. It shall rest upon the upper border of the leg socket by means of a ledge of one or more pieces of sole leather attached to its front surface just below the edge. Instead of or in addition to this it may be slung from the lower edge of the thigh corset by leather straps and buckles or by a continuous piece of soft leather.

13. **Shin Piece.**—The shin piece may be made separate from the socket, in which case it shall be fixed to the socket by at least four soft wood keys, diagonally placed, mortised into the two sections and securely glued.

14. **Rawhide Covering.**—The leg socket and shin piece shall be covered with a suitable rawhide, securely fastened by best Scotch glue applied hot, shellac finished and polished. The rawhide s all completely cover the side straps.

The specification for the remainder of this limb is the same as that for the No. 1 Limb (A), Sections 26 to 39.

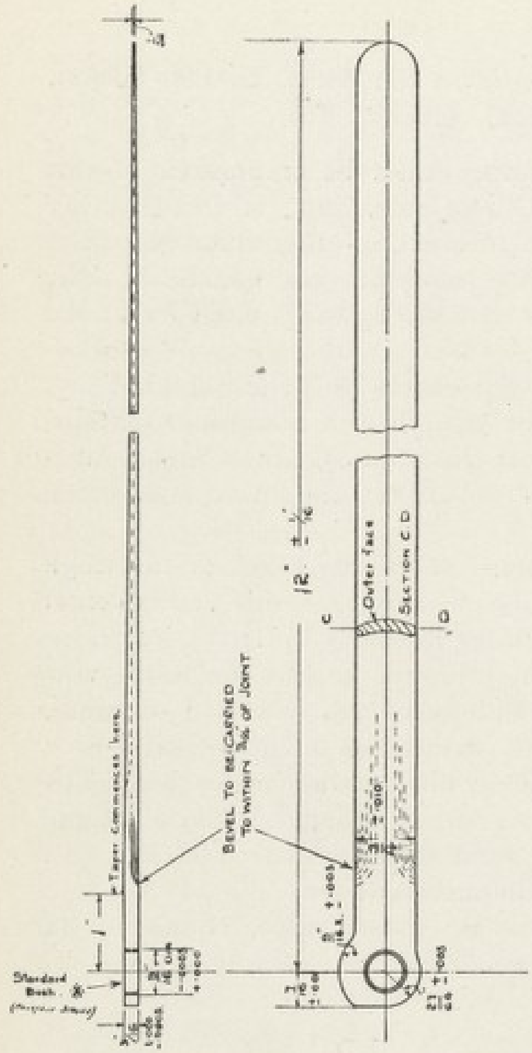


Fig. 252.—Straight Upper Steel for Through Knee and Kneeling Legs.

From Blue Print No. S. 100.

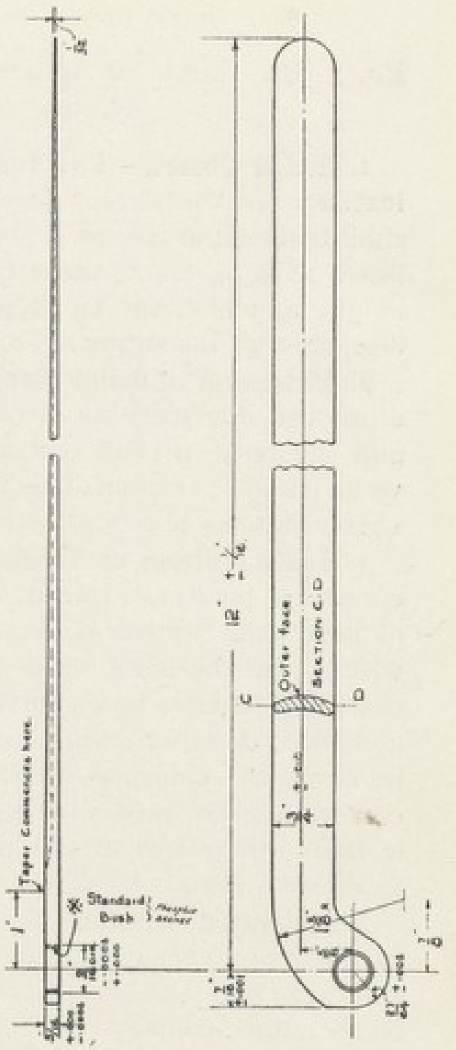


Fig. 253.—Offset (Eccentric) Upper Steel for Below Knee Legs.

From Blue Print No. S. 101.

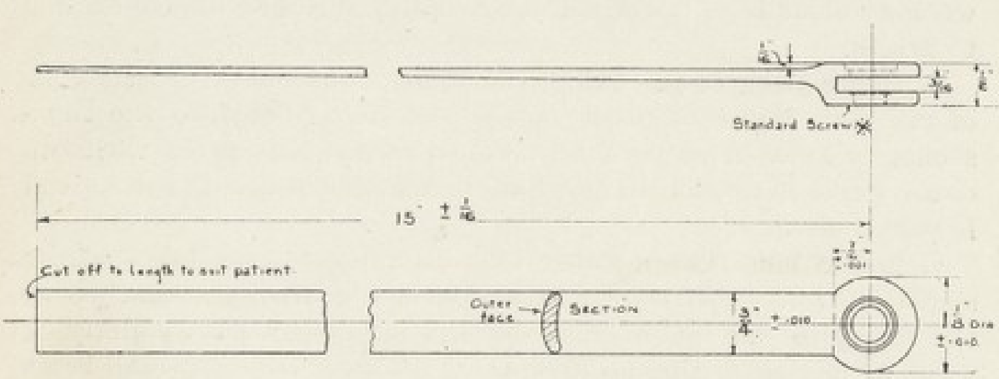


Fig. 254.—Knee-Joint, Lower Steel, for Below Knee Leg (Leather Socket only).

From Blue Print No. S. 102.

No. 8 (H).—Limb for Amputation Below the Knee (Leather Socket, Lacing at Back) (see Fig. 255).

1. **Thigh Corset.**—The thigh corset shall be of blocked or soft leather. In the former case, the best sole, butt, or bend leather shall be used; in the latter, chrome, tanned, or other suitable leather lined with doeskin, sheep, or soft Helvetia (not chamois). The height to which the thigh corset extends upwards shall be at the discretion of the surgeon.

2. **Extension of Thigh Corset.**—The extension of the thigh corset down the side steels shall be made to suit each individual patient, and the surgeon shall advise whether or not an above knee transverse leather strap shall be attached between the lower edge of the corset and the knee-joint.

3. **Lacing Pieces of Thigh Corset.**—When the edges of the thigh corset are made to overlap, a lacing piece on each side of the corset of best stout upper or other suitable leather, $1\frac{1}{4}$ to $1\frac{1}{2}$ inches in width, shall be hand sewn with best waxed thread the whole way down the corset, and punched to allow of the insertion of brass, nickelled, or other suitable eyelets (with holes not less than $\frac{1}{4}$ inch in diameter) clenched on the inside flush with the leather. The corset shall be laced with a grease-tanned thong. When a tongue is fitted, the edges of the corset shall themselves be punched and fitted with eyelets in the manner described above.

4. **Extension Elastic.**—A forked extension piece, consisting of two leather straps cut out of one piece, shall be extended a sufficient distance down the shin piece, and securely attached thereto by two No. 8 I.W.G. copper rivets.

5. **Elastic Back Lift.**—A leather tab 2 inches wide by $3\frac{1}{2}$ inches long shall be attached to the back of the thigh corset by three No. 8 I.W.G. copper rivets, to which shall be securely stitched a piece of elastic webbing 2 inches wide. The upper end of the elastic webbing shall have a leather tab securely stitched for connection to braces.

6. **Upper Back Check Tab.**—The upper back check tab shall be of the best bridle or other suitable leather, riveted to the thigh socket or hand sewn with best waxed thread, and fitted with two or more eyelets to allow the rawhide thong to be inserted, as described in paragraph 3.

7. **Lower Back Check Tab.**—The lower back check tab shall be similar to that described in paragraph 4. It shall be attached to the shin piece by two or more brass wood screws with underlying washers, and be further secured along its lower edge by small brass pins. The necessary eyelets shall be fixed for the insertion of the rawhide thong. If it is placed above the wooden portion of the leg socket, it shall be attached to the leather portion of the leg socket

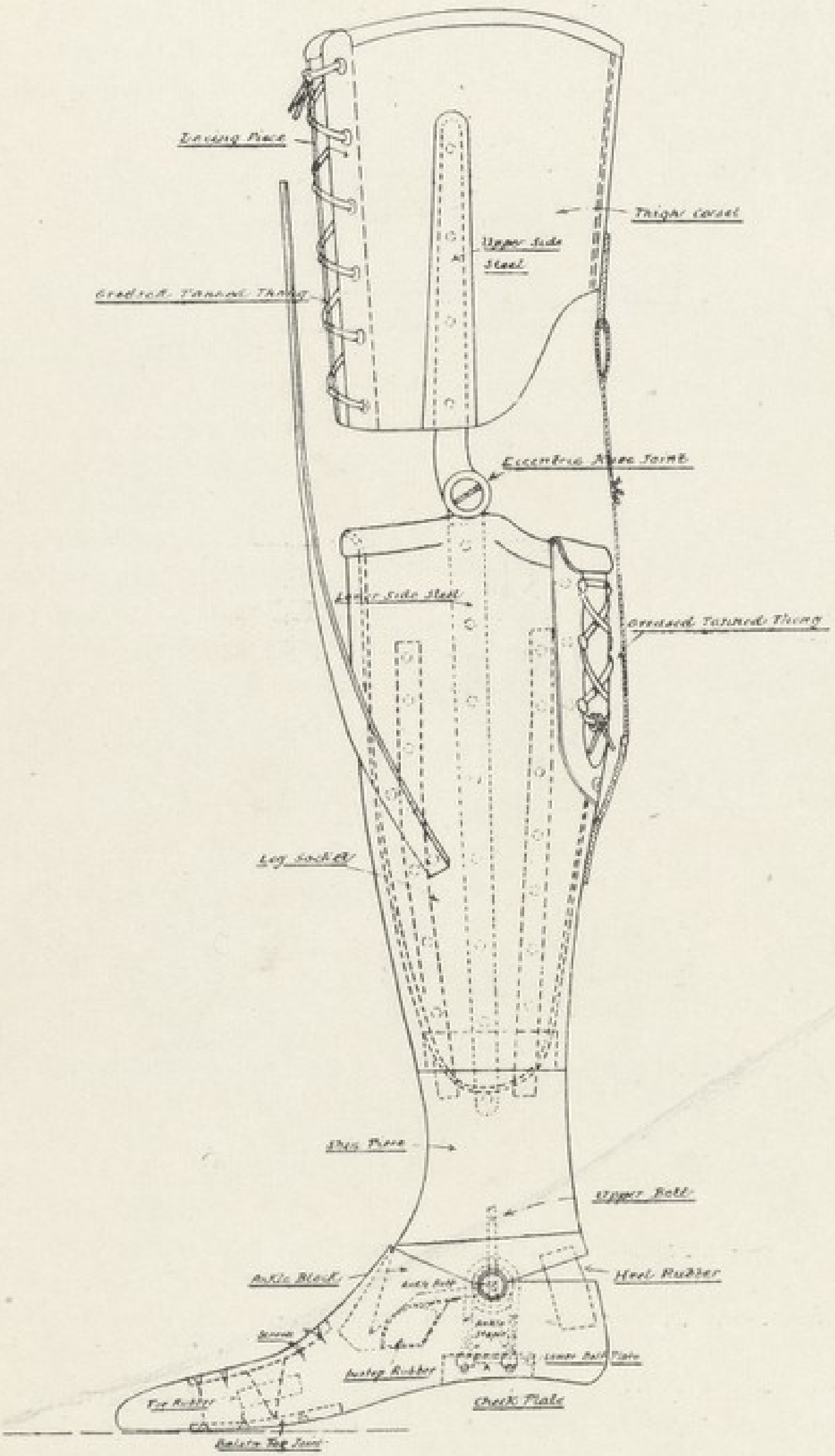


Fig. 255.—Below Knee Leg, No. 8 (H): Leather Socket.

by one No. 8 I.W.G. copper rivet as well as securely hand stitched thereto.

8. **Knee-Joint.**—The knee-joint is shown in Blue Prints Nos. S. 101 and S. 102. The upper arm of the joint (S. 101) shall be attached to the thigh corset by three No. 8 I.W.G. copper rivets, and pro-

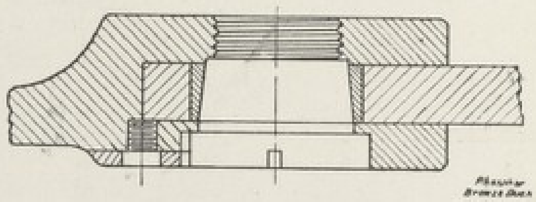


FIG. 256.—STANDARD JOINT.
About 1½ times actual size.

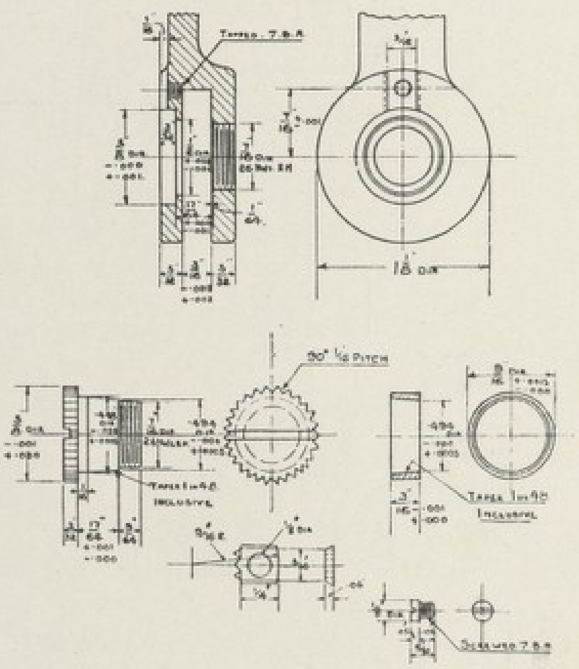


FIG 257.—STANDARD SCREW AND BUSH, ETC., FOR JOINTS NOS. S. 90, S. 91, S. 92, S. 98, S. 99, S. 100, S. 101, S. 102.
Details about three-quarters actual size. From Blue Print No. S. 103.

tected with a covering of suitable leather. The lower arm (S. 102) of the joint shall be sufficiently long to allow of its being fixed by No. 8 I.W.G. copper rivets (the heads of which shall be flush inside and out) to the wooden part of the leg socket as well as to the leather portion of the socket.

9. **Leg Socket.**—The leg socket shall be of best sole, butt, or bend leather moulded to fit the patient's stump, with a lap at back at least 1 inch in width skived to a knife edge, or the upper part of the socket may be closed with a V-shaped piece cut out above at the back for adjustment. In the latter case a tongue of bridle or other suitable leather shall be sewn to the leather socket at its lower end. The tongue shall be turned over the upper border of the socket, and be punched and eyeleted for the insertion of the lacing thong. The edges of the tongue within the socket to be skived to a knife edge.

10. **End Bearing.**—When ordered by the surgeon, an end bearing shall be fitted in this limb. It shall consist of a pad of best sponge rubber or other suitable material enclosed in an outer covering of chrome, tanned sheep, or other suitable leather, the edges of the covering to be securely stitched and not glued. It shall be supported by a rawhide thong laced through holes in the side of the socket or shin piece below the end of the stump.

11. **Ventilation Holes.**—Ventilation holes 1 inch in diameter shall be provided on either side of the shin piece below the extremity of the stump.

12. **Lacing Pieces of Leg Socket.**—When the edges of the leg socket are made to overlap, a lacing piece on each side of the socket of best stout upper or other suitable leather, 1¼ to 1½ inches in width, shall be hand sewn with best waxed thread (for a distance of 8 inches or more to suit the individual patient) down the socket, and punched to allow of the insertion of brass, nickelled, or other suitable eyelets (with holes not less than ¼ inch in diameter) clenched on the inside surface, and flush both inside and outside with the leather. The socket shall be laced with a grease-tanned leather thong. When the socket is closed below and a V-shaped piece cut out, the edges of this gap shall themselves be punched and fitted with eyelets in the manner described above.

13. **Shin Piece.**—The shin piece, or lower portion of the socket, shall be made of well-seasoned willow wood without detrimental cracks or shakes. It shall be overlapped by the leather socket at least 1 inch in depth, thereby forming a butt and lap joint. This butt joint shall be securely glued, and care taken that the inside of the wooden shin piece is skived down to a knife edge, so that the inside of the socket presents a perfectly even surface as far as practicable.

14. **Lining of Socket.**—The inside of the socket may be lined with chrome, doe, soft tanned sheep, or other suitable leather (not chamois) over a layer of felt if considered advisable. The upper edge of this lining shall be left long enough to overlap the top of the socket, and be securely fastened thereto. The lower edge of this lining shall also be securely glued to the interior of the socket. When the V-shaped type is made, the inside lining shall be long

enough to form a facing $1\frac{1}{2}$ inches in width on each side of the gap, and shall be securely fastened to the outside of the socket.

The specification for the remainder of this limb is the same as that for the No. 1 Limb (Wooden Socket) (A), Sections 26 to 39.

A. D. BAILEY,
Technical Adviser.

MINISTRY OF PENSIONS,
November, 1920.

APPENDIX II

DIRECTIONS FOR MAKING CERTALMID SOCKETS FOR ARTIFICIAL LEGS, AND FOR FITTING THE MINISTRY'S LIGHT METAL LEG. REPORT OF TESTS OF THE RELATIVE STRENGTH OF WOODEN AND OF CERTALMID SOCKETS.

Part 1.

1. **Partial Standardization and Preparation of Moulds for Sockets.**—The moulds may be made of either wood, plaster of Paris, or any other suitable material in series of sizes of rights and lefts as considered necessary by the limb makers.

A square tapered hole running through its length should be arranged to take a tapered stick, which, before inserting, should be dipped in paraffin wax; the object of the stick is to allow the mould to be held securely with a vice whilst moulding the material (see fig. 258, B).

The mould when perfectly smooth is ready for dipping in a cylinder containing hot paraffin wax. One dipping in a temperature of between 120° and 130° F. adds approximately $\frac{1}{16}$ inch thickness and dries immediately; to obtain a clean, smooth finish on the wax, rub any irregularities with a smooth, dry cloth.

The melting-point of the paraffin wax should be between 115° and 135° F., and by adding a lump of beeswax about the size of a hen's egg to 14 pounds of paraffin wax facilitates working and prevents the wax from becoming too brittle.

2. **Preparation of Muslin.**—Cut a paper templet of the size required to encircle the mould once, allowing an overlap of about 1 inch. To this size cut twelve pieces of coarse muslin No. 1, this quantity being sufficient for the average socket, the first six pieces being of the full length, the seventh piece 1 inch shorter, and each successive piece 1 inch shorter from the bottom than the previous piece; this will ensure the necessary taper of the thickness of the socket (see fig. 260, A).

With care the muslin can be cut into the required shapes without waste, and spare pieces of muslin should not be discarded, as they may be used for thickening up the socket under the ischium or other parts of the socket where extra strength may be required.

3. **Preparation of "Certalmid" Powder.**—The quantity of "Certalmid" powder to be mixed should not exceed 8 fluid ounces,

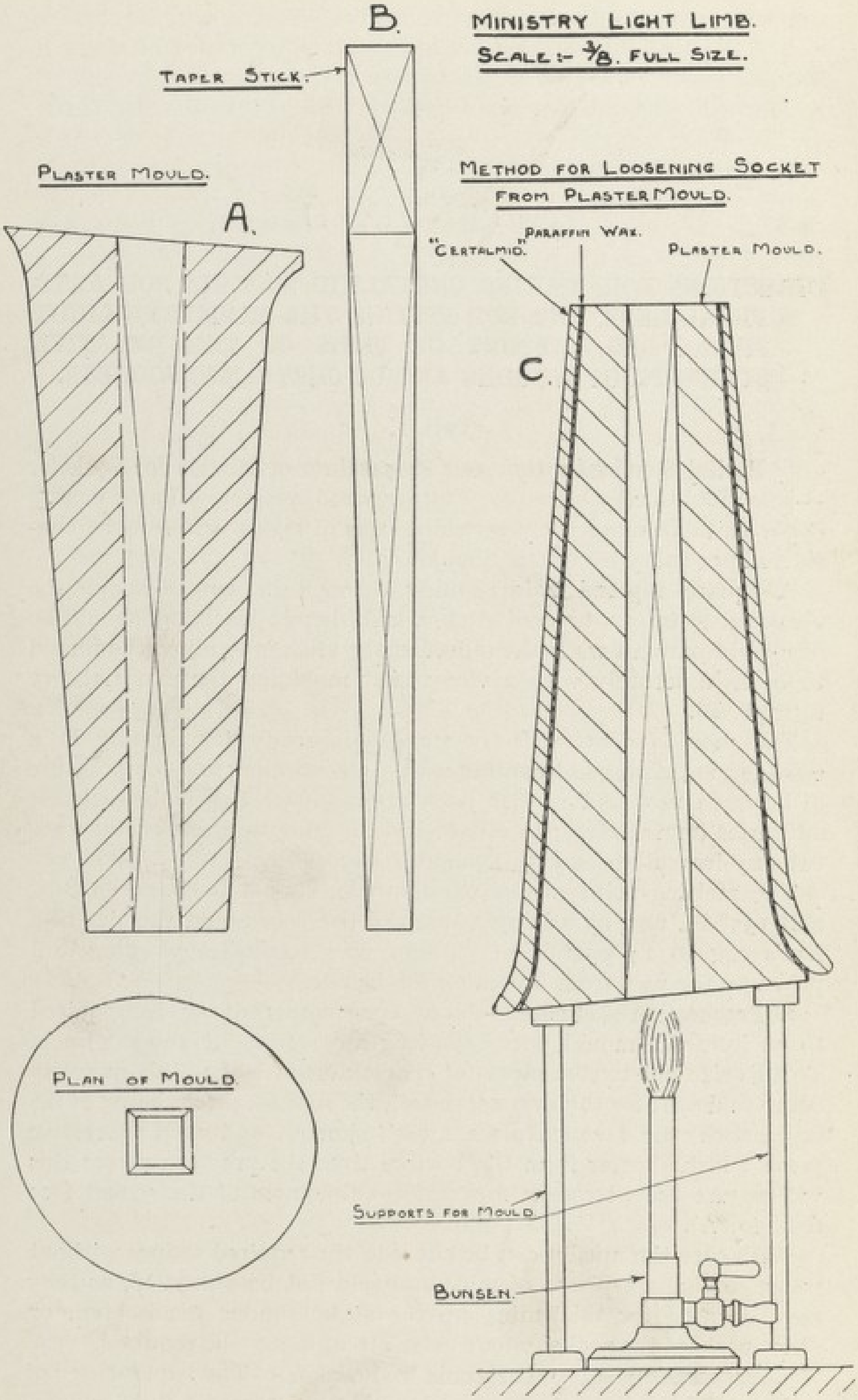


FIG. 258.—CERTALMID SOCKET.
Nearly one-fifth actual size.

which is sufficient for the average size socket. Place the powder in a small-sized mortar about 6 inches diameter (the advantage of a small vessel is that the mixture does not deteriorate so rapidly), to this add 6 fluid ounces of water, working up quickly with a pestle; allow the mixture to stand for ten minutes, during which time it should turn from a thick paste to a creamy liquid by chemical action; the addition of a little more water (say 1 or 2 ounces), added slowly while stirring briskly, makes the preparation ready for use. It should be noted that this mixture is not fit for use after two and a half hours.

4. **Application.**—The best method of application is with the hands protected with rubber gloves; the preparation should be smeared all over the surface of the mould previously covered with paraffin wax. A piece of muslin of the largest size should now be put on the smeared mould, carefully pressing out all creases, and the preparation again applied; another layer of muslin is added, taking care that the preparation of "Certalmid" percolates through each layer of muslin, as this creates a bond of union between the layers.

Unless the process is strictly carried out, the socket will be a failure.

The ischium should be reinforced between every alternate layer, or between each layer if considered necessary; also where the socket is intended to take a pelvic band it should be reinforced with muslin as follows: Eleven pieces of muslin should be cut, and when making the socket, as mentioned in the opening part of this paragraph, the pieces should be laid between every layer of muslin when applying, varying the position of them so that they do not leave too pronounced a patch; this can be done by altering the overlap either way a little each time.

If a stronger socket should be required, further layers of muslin may be added.

During the above process care must be taken that the overlapping of the muslin is distributed round the cast, otherwise a ridge will form.

5. **Drying and Hardening.**—An ideal temperature for quick drying is 70° to 80° F., or the sockets may be hung in a dry, warm shop, when they would be ready for removal from the mould in five to six days.

To remove the "Certalmid" socket from the mould, withdraw the square tapered stick from the mould, taking care that the paraffin wax surrounding it is also removed, place the mould on a tripod or any other suitable contrivance in such a position that the flame of a Bunsen burner can be placed directly under the hole from which the stick was removed. The heat softens the wax on the exterior of the mould (see fig. 258, C), and the socket should be ready to be detached in about thirty minutes.

A supplementary method is to apply either hot air or steam in a similar manner.

The above process having been carried out, it will be found that the "Certalmid" socket will be easily detachable without injuring the mould. The socket, having been detached, should now be allowed to dry thoroughly from the inside.

At this stage, when properly dried, the thickness at the top of the front side should be approximately $\frac{1}{8}$ inch, the lower end $\frac{1}{16}$ inch, and under the ischium $\frac{5}{16}$ inch thick.

6. **Fitting of Socket to Patient.**—For fitting, the patient should wear a thin stump sock. Select from stock the most suitable socket for the patient; the stump sock should be pulled into this with the aid of the stump sock, and any adjustments required can be done by cutting away with a spokeshave, saw, or knife any parts not required. The socket can also be built up in the following manner:

7. **Adding Laminations with Celluloid Solution.**—Coarse muslin No. 1 is used; pieces are cut to the desired sizes to make up the thickness required. The muslin is laid on the socket, and with a rake brush (as illustrated in fig. 259, A) brush the celluloid solution on, using sufficient solution to make the muslin adhere. Additional layers of muslin may be added in the same manner until the requisite thickness is obtained.

Part of the socket may be cut away in a circle or other suitable shape to avoid undue pressure on nerves, projections, or scars; the holes thus produced on the interior should be laminated on the exterior in the manner described above, pressure being maintained from the inside to preserve the requisite indentation.

If further reinforcement should be necessary in any part of the socket, it may now be done in the manner stated above. Laminations applied in this manner will be dry enough for fitting in about fifteen minutes.

8. **Socket for Abducted or Flexed Stump.**—If a patient has an abducted or flexed stump, provision for it may be made as follows:

The socket which fits the patient in the upper part should be cut away in a **V**-shape from whichever side it is necessary to suit the peculiarity of the stump (see fig. 260, C and D); the edges should then be brought together and bound with No. 1 muslin, and "Certalmid" overlapping at least 2 inches on each side of the cut (see fig. 260, E), and be allowed to dry, at the same time care being taken that the inside is made smooth.

9. **Ventilation Holes.**—Holes are drilled with a size $\frac{3}{8}$ Jennings wood twist bit in the manner shown in fig. 260, B, care being taken that these holes are placed so that a thin screwdriver may pass through them to reach the screws in the interior of the opposite wall which fasten the socket to the stanchions.

Elongated holes $1\frac{1}{2}$ by 3 inches long for drawing down the stump

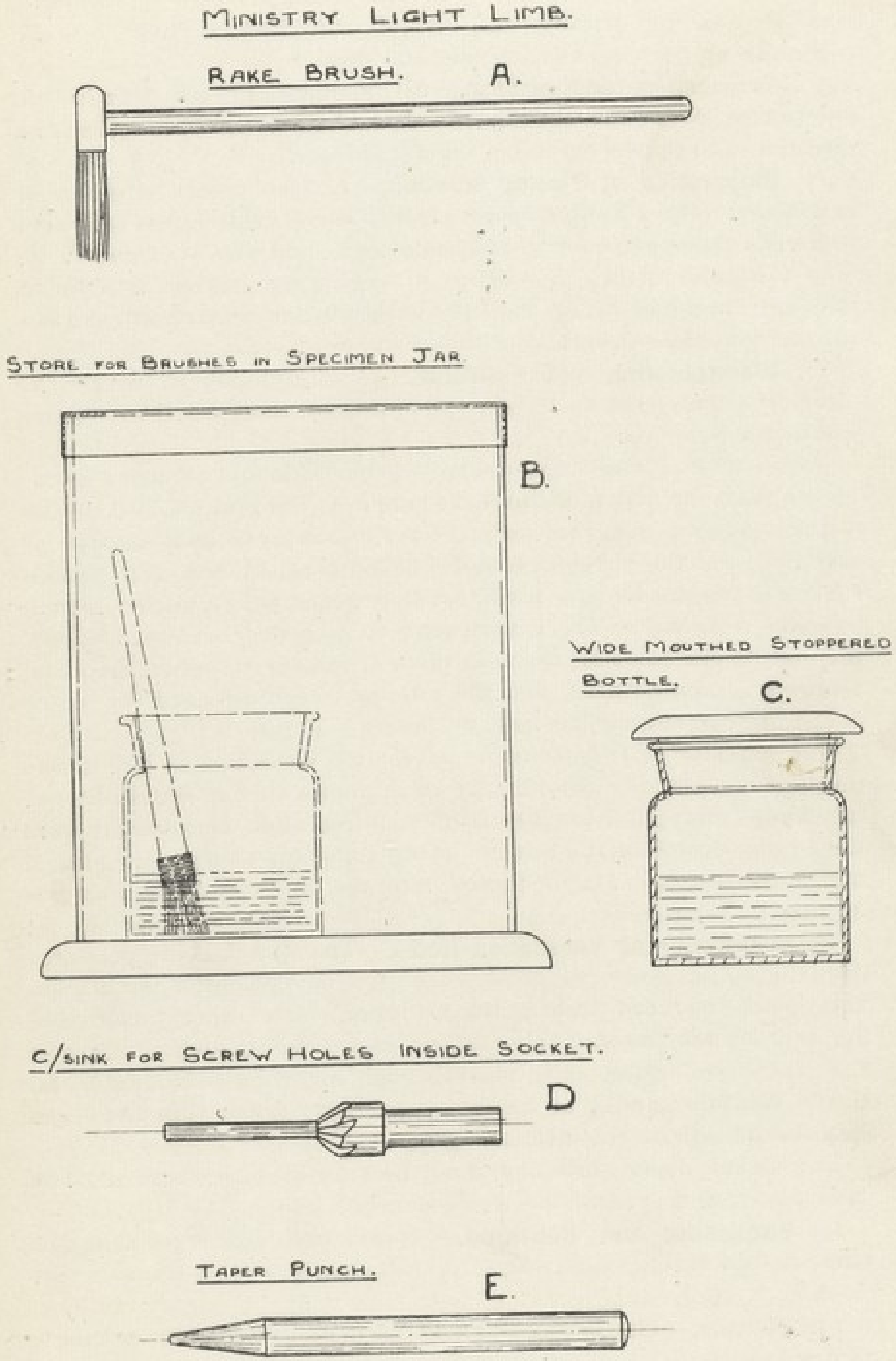


FIG. 259.
Nearly one-fifth of actual size.

sock in the socket should also be cut. The method of obtaining this shape is by drilling two 1½-inch holes with a twist bit and trimming up with a knife (see fig. 260, B).

10. **Preparation for Finishing.**—All blemishes on the interior and exterior of the socket should be well rubbed down with coarse and medium sand-paper, leaving a regular surface.

11. **Preparation of Tinting Solution.**—A flesh colour is obtained as follows: Take 2 milligrammes of scarlet 2 R (this is just sufficient to cover a threepenny piece, not heaped up), and dissolve this powder in a test-tube with a few drops of acetic acid, using as little as possible; then half fill up the tube with acetone, shake well, and stir into a Winchester quart of celluloid solution.

12. **Waterproofing and Finishing.**—It is difficult to cover the interior of the socket with one piece of muslin, therefore the following method is adopted:

Strips of No. 2 fine muslin 2½ to 3 inches wide and about 1½ inches longer than the depth of the socket are cut; the first piece of muslin is then laid on the inside lengthways, allowing ¾ inch overlap at each end, and the tinted celluloid solution brushed on to the exposed surface of the muslin with a rake brush (see fig. 259, A), using sufficient to make it adhere. The overlapping at each end is treated in this manner on the exterior, the next piece of muslin is applied similarly, allowing ⅛ inch overlap, and the process continued until the whole of the interior surface has had two layers of muslin.

The exterior of the socket receives two coverings of No. 2 fine muslin. As there is no difficulty in applying this, it should be put on in one piece, and the tinted celluloid solution brushed on from the outer surface of the muslin, using sufficient to make it adhere, and after an interval of fifteen minutes the second covering is applied in like manner.

13. **Waterproofing Ventilation Holes.**—The socket being perfectly dry, the outer covers of muslin are now covering the ventilation holes and stretched tightly across them. The taper punch (see fig. 259, E) for piercing these holes should be of such a diameter that the taper should only pass through up to half its length and tinted solution should be applied, care being taken that the edges shall be smooth on the interior.

The socket, being quite dry, must be rubbed with a smooth, fine sand-paper, and be made perfectly smooth.

14. **Varnishing and Polishing.**—Apply two coats of celluloid varnish (not tinted), and when dry rub lightly with a smooth, soft cloth.

15. **Utensils.**—The brushes should be kept in acetone, as shown in fig. 259, B.

Celluloid solution should be stocked in 8-ounce, wide-mouth, stoppered bottles (see fig. 259 ,C).

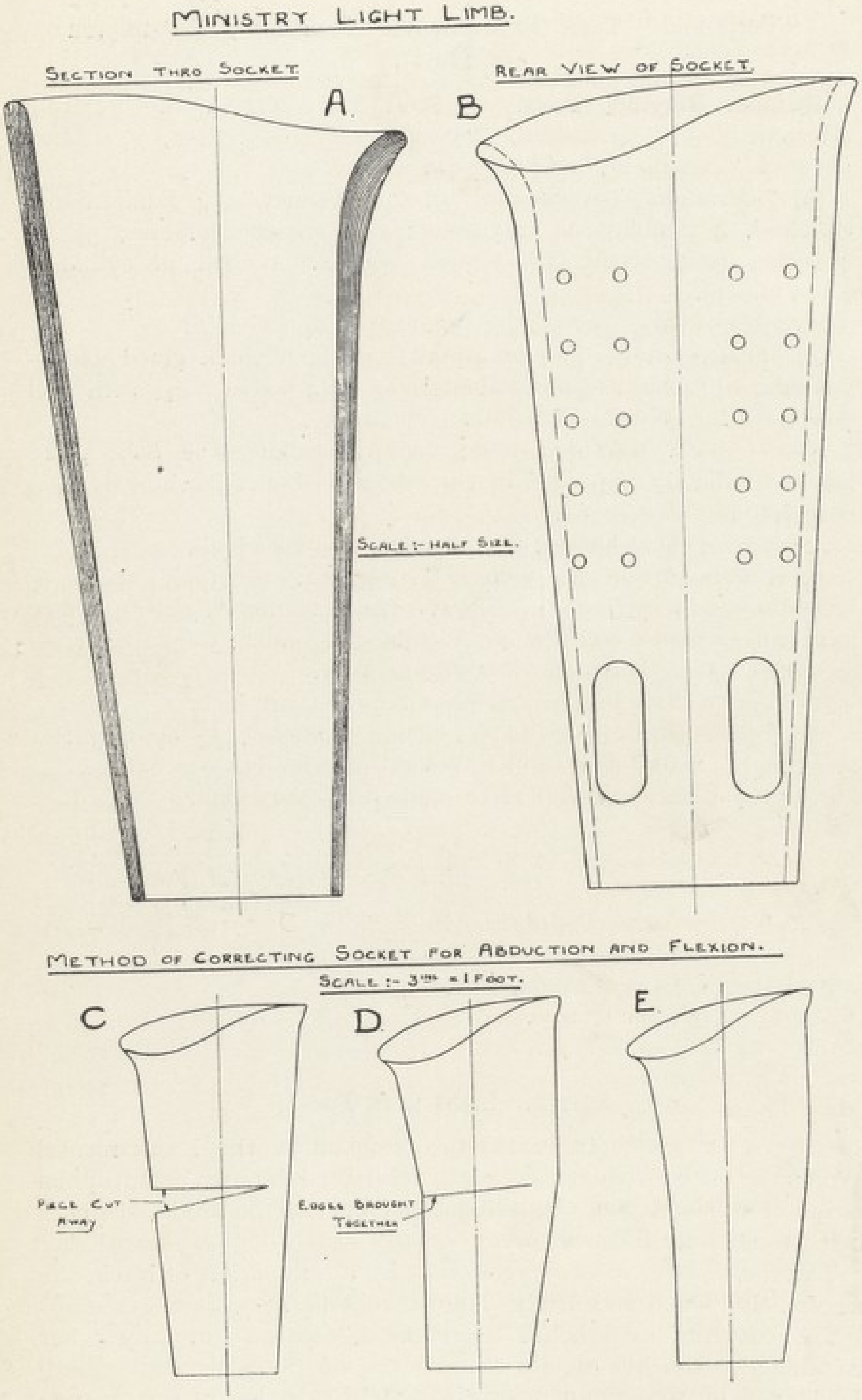

MINISTRY LIGHT LIMB.
SECTION THRO SOCKET.
REAR VIEW OF SOCKET.
A.
B
SCALE :- HALF SIZE.
METHOD OF CORRECTING SOCKET FOR ABDUCTION AND FLEXION.
SCALE :- 3INS = 1 FOOT.
C
D
E
PIECE CUT AWAY
EDGES BROUGHT TOGETHER

FIG. 260.

"Certalmid" Tests (Experimental Workshops, Roehampton House).

Cylinder Bursting Tests.—Objects: To ascertain the bursting strength of (*a*) "Certalmid," (*b*) willow-covered vellum, (*c*) willow-covered "Certalmid," and (*d*) plain willow.

(*a*) "*Certalmid.*"—Consisting of "Certalmid," 14 laminations; celluloid, 4 laminations. Cylinder: size, inside diameter, 3½ by 4 inches long, with wall ⅛ inch approx. Weight of cylinder: 2·125 ounces.

Average of three bursts: 332 pounds per square inch.

(*b*) *Willow-covered Vellum* (approx. $\frac{1}{32}$ inch thick glued on).—Cylinder of willow: inside diameter, 3½ by 4 inches long, with wall ⅜ inch thick. Weight of cylinder: 5·2 ounces.

Note.—Wood fractured first; vellum bridging the gap; more fractures shortly appeared in the wood; vellum stretching until a complete burst occurred.

Average of three bursts: 301 pounds per square inch.

(*c*) *Willow-covered "Certalmid"* (approx. $\frac{1}{32}$ inch thick).—Laminated on to cylinder of willow. Inside diameter, 3¼ by 4 inches long, with a wall ⅜ inch thick. Weight of cylinder: 5·03 ounces.

Note.—Materials fractured simultaneously.

Average of three bursts: 258 pounds per square inch.

(*d*) *Willow* (*Plain*).—Cylinder: inside diameter, 3¼ by 4 inches long, with a wall ⅜ inch thick. Weight of cylinder: 3·56 ounces.

Average of three bursts: 129 pounds per square inch.

(*Signed*) HENRY LONGMATE, A.M.I.Mech.E.,
Superintendent Experimental Workshops,
Artificial Limb Section, M.O.P.

ROEHAMPTON HOUSE,
ROEHAMPTON LANE, LONDON, S.W. 15,
December 6, 1920.

Part 2.—Light Cork Foot.

The "C" type light cork foot, designed at the Experimental Workshop, is constructed of cork, reinforced by two longitudinal strips of willow, which take the greater part of the strain, the cork being used to form the shape.

The toe piece is of cork, reinforced by a lamination of birch, the whole being glued and firmly clamped together.

The covering may be of "Certalmid," leather, or any other suitable material (see fig. 261).

The weight of the foot is approximately half that of the average wooden foot, being between 6 and 7 ounces.

The foot is being well tried out, and, so far, very satisfactory results have been obtained.

The advantage derived in walking by any reduction in weight at the lower extremity of the limb will be readily understood.

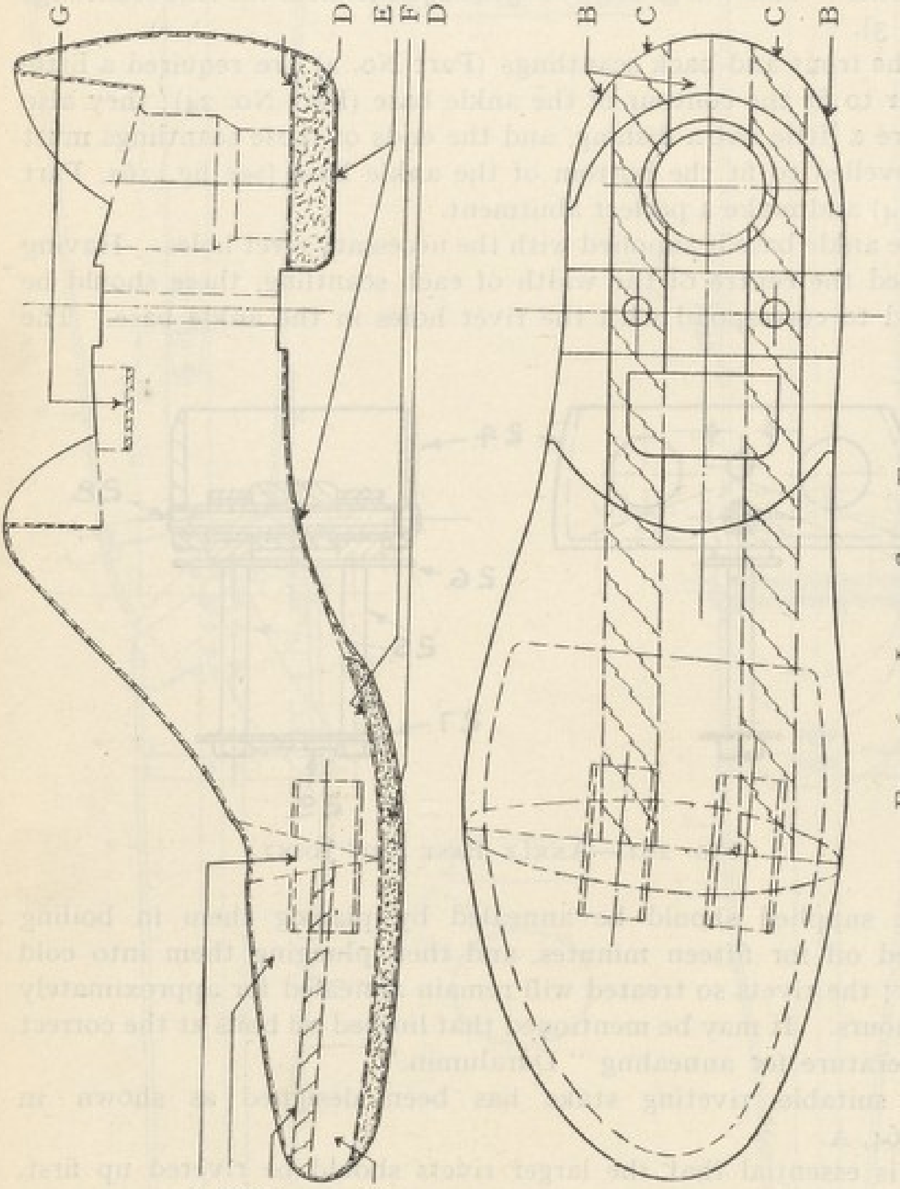


FIG. 261.—LIGHT CORK FOOT.
A, Rubber toe spring; *B,B*, cork; *C,C*, wood; *D,D*, sponge rubber; *E*, certalmid; *F*, toe-hinge; *G*, bed for instep rubber spring.

Part 3.—Assembling and Fitting.

16. **Metal Unit.**—The metal components are supplied assembled as shown in fig. 264. This unit is standardized and designed for the right or left leg, and the scantlings are sufficiently long to fit the majority of cases.

When the unit is supplied without the ankle base fitted, it is necessary to detach the knee part by extracting the knee bolt

(Part 7) and removing the lower back tendon bracket (Part 9, Drawing 121, see fig. 263).

17. **Fitting Ankle Base.**—Having ascertained the length required from the centre of the patient's knee-joint to the ground, deduct 2½ inches. This will give the length required from the side scantlings (Part 3).

The front and back scantlings (Part No. 4) are required a little longer to fit the contour of the ankle base (Part No. 24); they also require a little extra dishing, and the ends of these scantlings must be bevelled to fit the bottom of the ankle base (see fig. 262, Part No. 24) and make a perfect abutment.

The ankle base is supplied with the necessary rivet holes. Having marked the centre of the width of each scantling, these should be drilled to correspond with the rivet holes in the ankle base. The

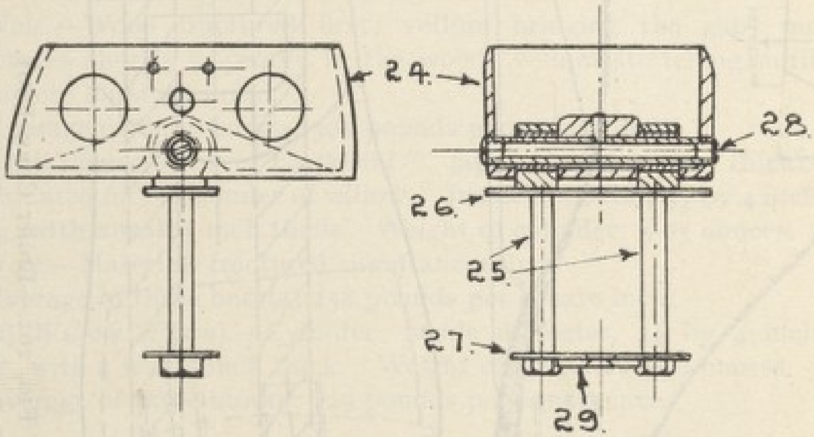


FIG. 262.—ANKLE BASE AND JOINT.

rivets supplied should be annealed by placing them in boiling linseed oil for fifteen minutes, and then plunging them into cold water; the rivets so treated will remain annealed for approximately two hours. It may be mentioned that linseed oil boils at the correct temperature for annealing "Duralumin."

A suitable riveting stake has been designed as shown in fig. 264, A.

It is essential that the larger rivets should be riveted up first, making sure that a perfect clench is obtained; finish with a doming punch. Then the smaller rivets are fixed in a similar manner.

18. **Leg Rings.**—Two are supplied as Part No. 15. These should be placed at equal distance between the bottom surface of ankle ring (Part 6) and the top of ankle base (Part 24).

Thin vellum 0·020 inch thick having been introduced between the scantlings and the rings, the two latter are now riveted up with three rivets to each of the scantlings except the back one, which should have four rivets, care being taken that each rivet is drawn up tightly with a good domed head.

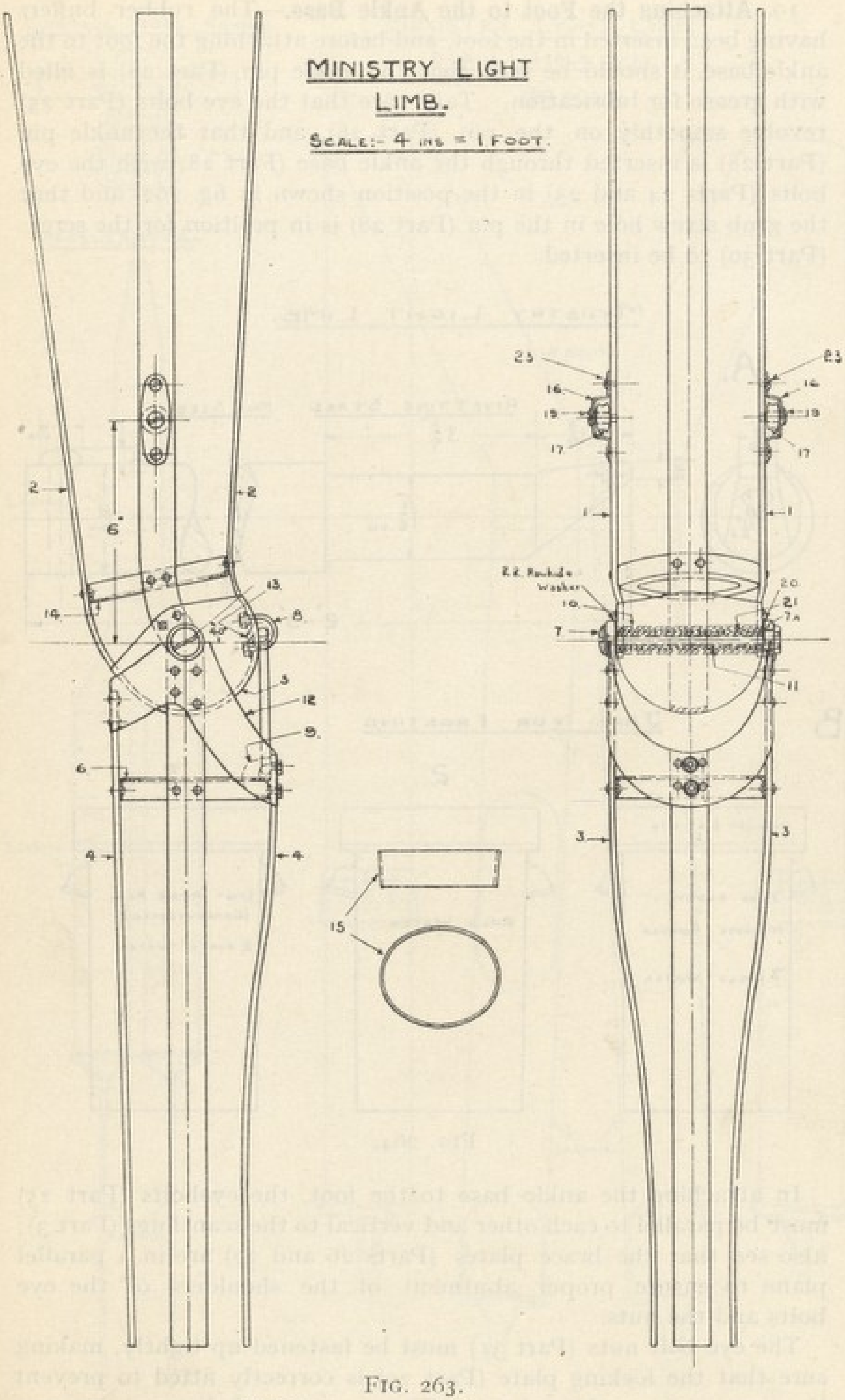


FIG. 263.
A little over one-sixth actual size.

19. **Attaching the Foot to the Ankle Base.**—The rubber buffers having been inserted in the foot, and before attaching the foot to the ankle base, it should be seen that the ankle pin (Part 28) is filled with grease for lubrication. Take care that the eye bolts (Part 25) revolve smoothly on the pin (Part 28), and that the ankle pin (Part 28) is inserted through the ankle base (Part 28) with the eye bolts (Parts 24 and 25) in the position shown in fig. 262, and that the grub screw hole in the pin (Part 28) is in position for the screw (Part 30) to be inserted.

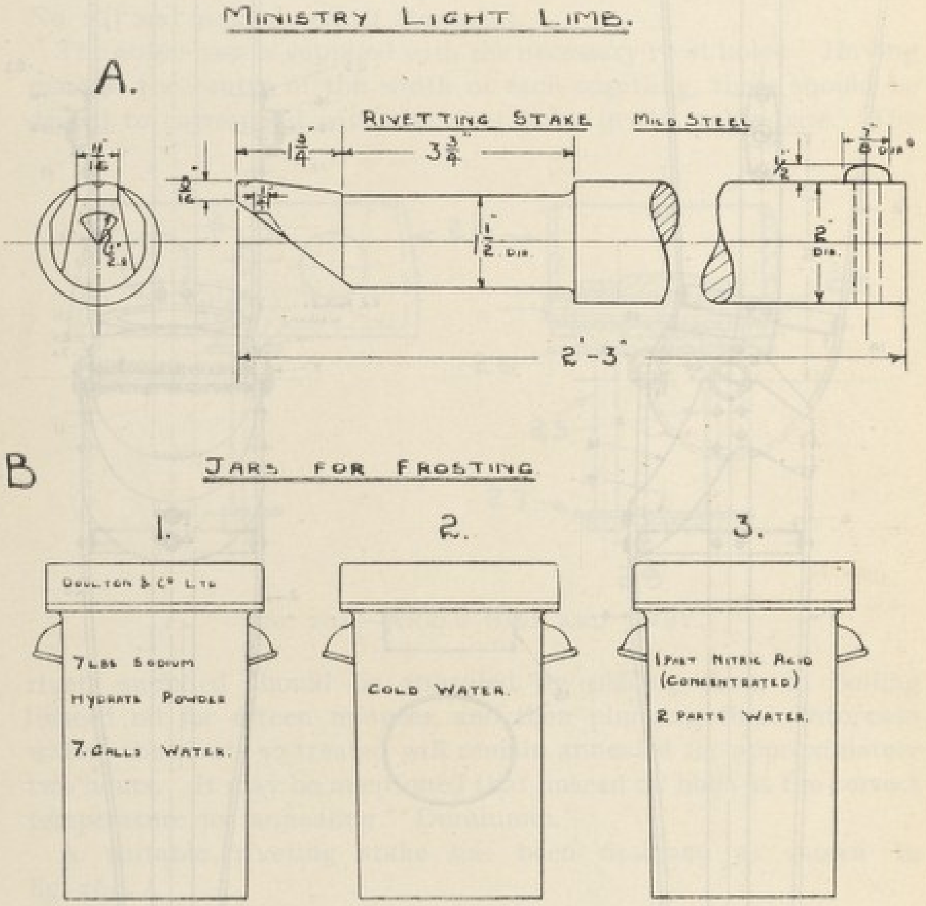


FIG. 264.

In attaching the ankle base to the foot, the eyebolts (Part 25) must be parallel to each other and vertical to the scantlings (Part 3); also see that the brace plates (Parts 26 and 27) are in a parallel plane to ensure proper abutment of the shoulders of the eye bolts and the nuts.

The eye bolt nuts (Part 31) must be fastened up tightly, making sure that the locking plate (Part 29) is correctly fitted to prevent the nuts from working loose. The counter-sunk brass screw may now be inserted.

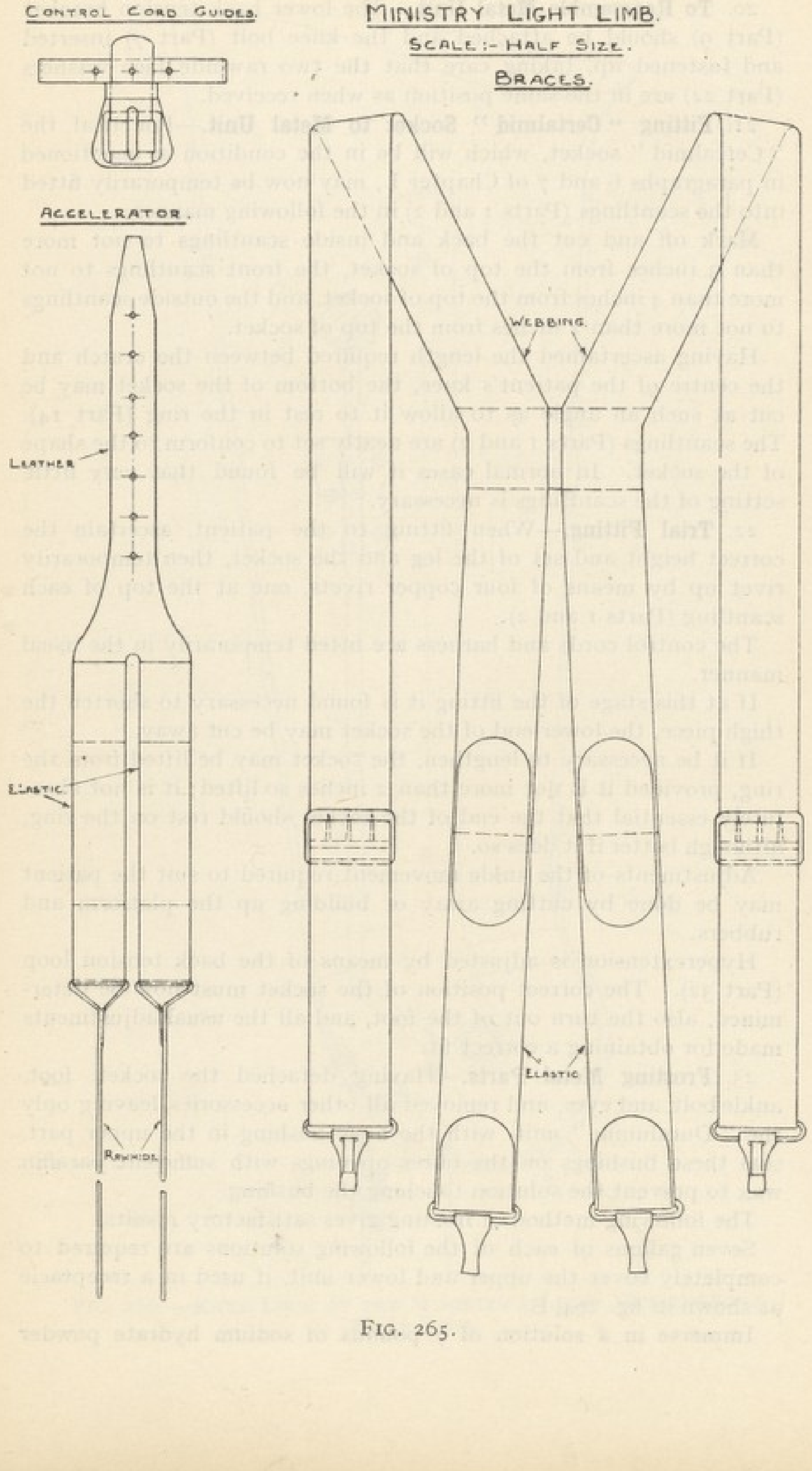

Control Cord Guides.
Ministry Light Limb.
Scale:- Half Size.
Braces.
Accelerator.
Webbing.
Leather
Elastic
Elastic
Rawhide

FIG. 265.

20. **To Reassemble Metal Unit.**—The lower back tension bracket (Part 9) should be attached and the knee bolt (Part 7) inserted and fastened up, taking care that the two rawhide face washers (Part 22) are in the same position as when received.

21. **Fitting "Certalmid" Socket to Metal Unit.**—For trial the "Certalmid" socket, which will be in the condition as mentioned in paragraphs 6 and 7 of Chapter I., may now be temporarily fitted into the scantlings (Parts 1 and 2) in the following manner:

Mark off and cut the back and inside scantlings to not more than 3 inches from the top of socket, the front scantlings to not more than 4 inches from the top of socket, and the outside scantlings to not more than 2 inches from the top of socket.

Having ascertained the length required between the crutch and the centre of the patient's knee, the bottom of the socket may be cut at such an angle as to allow it to rest in the ring (Part 14). The scantlings (Parts 1 and 2) are neatly set to conform to the shape of the socket. In normal cases it will be found that very little setting of the scantlings is necessary.

22. **Trial Fitting.**—When fitting to the patient, ascertain the correct height and set of the leg and the socket, then temporarily rivet up by means of four copper rivets, one at the top of each scantling (Parts 1 and 2).

The control cords and harness are fitted temporarily in the usual manner.

If at this stage of the fitting it is found necessary to shorten the thigh piece, the lower end of the socket may be cut away.

If it be necessary to lengthen, the socket may be lifted from the ring, provided it is not more than 2 inches so lifted; it is not absolutely essential that the end of the socket should rest on the ring, although better if it does so.

Adjustments of the ankle movement required to suit the patient may be done by cutting away or building up the platform and rubbers.

Hyperextension is adjusted by means of the back tension loop (Part 32). The correct position of the socket must now be determined, also the turn out of the foot, and all the usual adjustments made for obtaining a correct fit.

23. **Frosting Metal Parts.**—Having detached the socket, foot, ankle bolt, and eyes, and removed all other accessories, leaving only the "Duralumin" unit, with the knee bushing in the upper part, seal these bushings on the outer openings with sufficient paraffin wax to prevent the solution touching the bushing.

The following method of frosting gives satisfactory results:

Seven gallons of each of the following solutions are required to completely cover the upper and lower unit, if used in a receptacle as shown in fig. 264, B.

Immerse in a solution of 7 pounds of sodium hydrate powder

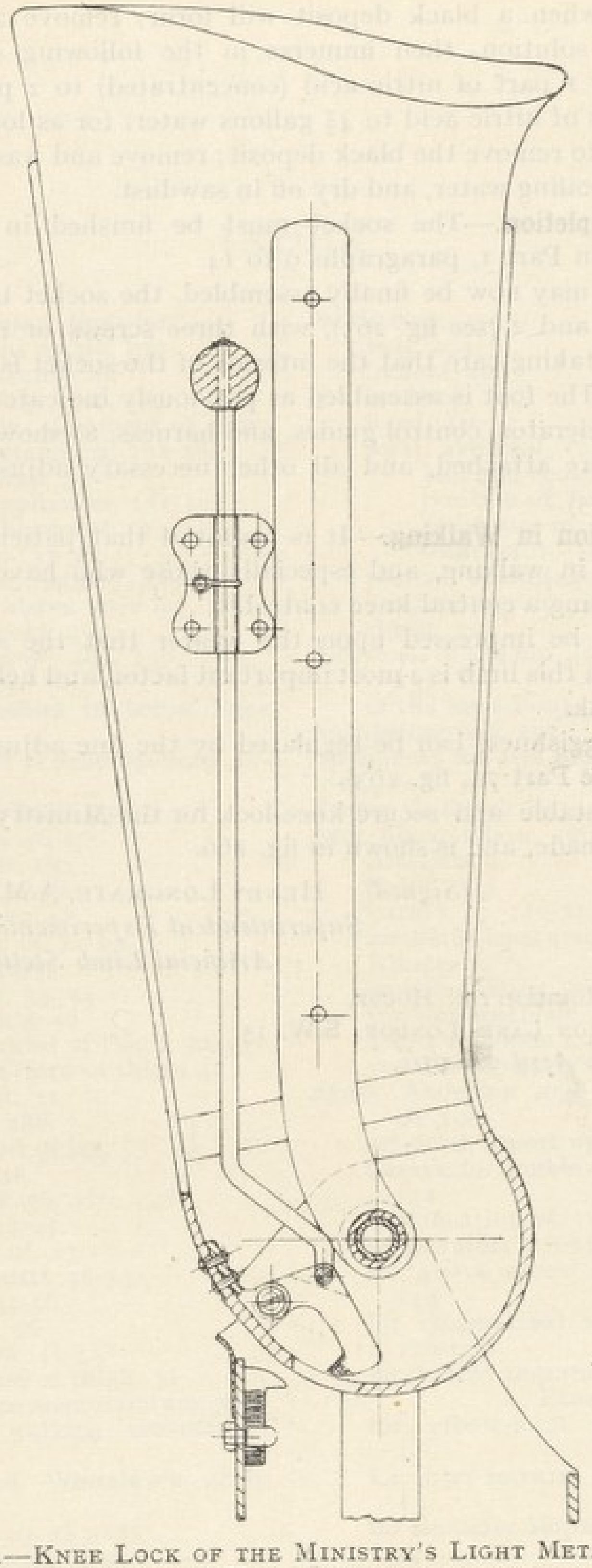


Fig. 266.—Knee Lock of the Ministry's Light Metal Above Knee Limb.

(98 per cent.) dissolved in 7 gallons of water, used cold, for ten minutes, when a black deposit will form; remove and wash off excess of solution, then immerse in the following solution, also used cold: 1 part of nitric acid (concentrated) to 2 parts of water ($2\frac{1}{3}$ gallons of nitric acid to $4\frac{2}{3}$ gallons water) for as long as may be necessary to remove the black deposit; remove and wash thoroughly in hot or boiling water, and dry off in sawdust.

24. **Completion.**—The socket must be finished in the manner described in Part 1, paragraphs 9 to 14.

The leg may now be finally assembled, the socket being fastened to Parts 1 and 2 (see fig. 263), with three screws or rivets in each scantling, taking care that the interior of the socket is left perfectly smooth. The foot is assembled as previously indicated.

The accelerator, control guides, and harness, as shown in Drawing No. 122, are attached, and all other necessary adjustments made (see fig. 265).

25. **Tuition in Walking.**—It is essential that patients should be instructed in walking, and especially those who have been in the habit of using a central knee control.

It must be impressed upon the wearer that the sluggish knee provided in this limb is a most important factor, and helps to develop a good walk.

This sluggishness can be regulated by the fine adjustment under the nut (see Part 7A, fig. 263).

An adjustable and secure knee-lock for the Ministry Light Limb has been made, and is shown in fig. 266.

(*Signed*) HENRY LONGMATE, A.M.I.Mech.E.,
Superintendent Experimental Workshops,
Artificial Limb Section, M.O.P.

ROEHAMPTON HOUSE,
ROEHAMPTON LANE, LONDON, S.W. 15,
April 28, 1921.

INDEX

H. K. LEWIS & CO. LTD., 28, GOWER PLACE, LONDON, W.C. 1

ARTIFICIAL LIMBS AND AMPUTATION STUMPS

E. MUIRHEAD LITTLE

WITH ILLUSTRATIONS

LEWIS'S PRACTICAL SERIES