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Read May 13th,

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Received January 12th—Read May 11th, 1886.

I.—*Object of Paper.*

The object of this communication is to show that, in the ligature of a large artery in its continuity, it is neither necessary nor advisable to tie the ligature so tightly as to rupture the coats of the vessel; and, further, to demonstrate that a small round ligature possessed of certain qualities and used with the least possible disturbance of the sheath of the vessel is the best for the purpose.

With reference to the occlusion of the smaller arteries, such as the radial, and to the ligature of the cut ends of arteries large or small in an amputation stump, we are not now concerned. In the former case such vessels do not require any special precautions or methods in order to ensure their safe obliteration, and in the latter the question must be looked at from a different point of view.

II.—*Historical Sketch.*

Centuries before the discovery of the circulation[1] of the blood the ligation of arteries for wounds[2] and aneurisms[3] was practised. A great diversity of opinion has always existed as to the best method of performing the operation. The practice of surgeons from the earliest times to the present day seems to have been based on one or other of two great opposing principles:

[1] Harvey, 'De motu cordis et sanguinis,' 1618.

[2] Celsus (book v, chapter 26, paragraph 21):—"But if pressure and astringents are ineffectual to restrain the hæmorrhage, the bleeding vessel is to be taken up, and a ligature having been applied on each side of the wound in it, the vessel is then to be divided; the two parts of the vessel will become united by anastomosing branches, and the orifices will become obliterated."

[3] Galen (Kuhn's edition, chap. 23, vol. xi, p. 313):—"If the artery be large, and if it be cicatrized beyond the aneurism, the whole of it should be cut through, and oftentimes that very practice prevents the danger from hæmorrhage; for it appears plainly that when a complete transverse division is made both portions of the artery retract on either side, the one above the part, the other below." Paré (Works, 1579, translation by Johnson, 1665, p. 323), was the great advocate of the ligature after Galen. He says, concerning the stanching of bleeding in amputation: "The ends of the vessels lying hid in the flesh, must be taken hold of and drawn with this instrument (forceps) forth of the muscles, whereinto they presently after the amputation withdrew themselves. In performance of this work, you need take no great care, if you together with the vessels comprehend some portion of the neighbouring parts, as of the flesh, for hereof will ensue no harm; but the vessells will so be consolidated with more ease, than if they being bloodlesse parts should grow together by themselves." P. 325:—"Wherefore I must earnestly entreat all Chirurgeons, that leaving this old and too cruel way of healing [actual cautery], they would embrace this new, which I think was taught me by the special favour of the sacred Deity; for I learnt it not of my masters, nor of any other; neither have I at any time found it used by any; only I have read it in Galen, that there was no speedier remedy for stanching of blood, than to bind the vessels (through which it flowed) towards their roots, to wit, the liver and heart. This precept of Galen, of binding and sowing the veins and arteries in the new wounds, when as I thought it might be drawn to these which are made by the amputation of members, I attempted it in many." Ambrose Paré, 1582 (Paré, Works, Lyon, 1641, quoted by Erichsen):—"Divide the skin above the aneurism, and, separating the artery, pass a seton needle armed with a strong thread under it, and allow the ligature to fall of itself. Nature will then generate flesh which will block up the artery."

1. That of tying with considerable force in the belief that damage to the arterial wall was either essential to obliteration or a necessary safeguard against hæmorrhage.

2. That of treating the artery with gentleness in the endeavour to cause its obliteration without inflicting the least injury to it.

The earlier surgical writers, Galen,[1] Paulus Ægineta,[2] and others recommend the application of two ligatures and the division of the artery between them; an operation which now bears the name of Abernethy[3] (1827), but many others have practised it. This way of tying an artery probably originated in the observation that arteries in amputation stumps are less prone to secondary hæmorrhage than those tied in continuity; a fact which explains the favour with which the operation has lately been received, and gives the reason for its attempted revival.[4] The validity of this analogy was questioned by Sir Charles Bell[5] sixty years ago, and the procedure appears unnecessarily severe.

The earlier surgeons belong to the severer school, and with them must be placed Jones[6] (1805), who from experiments upon the lower animals considered that he had demonstrated conclusively that the tunics should be ruptured in tying an artery in its continuity. He advocated also the isolation of the vessel and the use of the small round ligature. He says you must divide the two inner coats because if you do not adhesion will not take place, and, as the ligature ulcerates through, hæmor-

[1] Loc. cit.

[2] Paulus Ægineta (seventh century):—"The artery having been cleared of the surrounding parts is to be exposed with the same scalpels with which the membranes have been divided; a needle being then passed under it, the artery is to be tied with a double ligature, having previously been punctured in the middle; suppuration must then be promoted till the ligatures fall out." ('Observations on Aneurism,' collected and translated by John Erichsen, Sydenham Society, 1844.)

[3] Abernethy, Surgical Works, new edit., 1827.

[4] Walsham, 'Brit. Med. Journ.,' 1883, vol. i, p. 660.

[5] Bell, 'The Great Operations of Surgery,' 1821.

[6] Jones, 'On Hæmorrhage,' 1805, p. 170.

rhage will occur. And again, "I cannot be expected to illustrate these opinions by cases, nor would it be easy to confirm them on dogs, for whom nature does so much." Thus Jones made no experiment upon the effect of *not* dividing the coats; he inferred it from the process of repair in nature in wounded arteries, but *if the coats are not cut the artery is not wounded.* It is upon this insecure basis that the established rule of the present day, with regard to the treatment of the wall of the vessel, rests. The majority of English surgeons adopted the views of Jones. In 1813 and 1815 Travers[1] reported his experiments to this Society and recommended the employment of the temporary ligature, and also, as an indispensable condition of obliteration, the rupture of the tunics.

The milder treatment of the wall of the artery has, however, long had its advocates. Alexander Monro[2] (1725) employed a wide ligature not drawn very tight to avoid injuring the vessel. Benjamin Bell[3] (1787) writes, in his 'System of Surgery,' "There is no occasion whatever for making the ligature so tight on arteries as to run any risk of dividing them; a much less degree of pressure than is commonly applied, or could have any influence in hurting them, being fully sufficient for compressing them in the most effectual manner." The best known advocate of gentleness is Scarpa[4] (1817), who was investigating the subject in Italy about the same time that Jones was at work in England. To him is undoubtedly due the honour of demonstrating that the rupture of the coats of an artery is not necessary for its obliteration by ligature. He employed a tape ligature to avoid damage to the arterial wall, and inserted a cylinder of lint between the ligature and the vessel, so as to flatten the latter. The ligature and cylinder were removed on the third, fourth, or fifth

[1] 'Med.-Chir. Trans.,' vol. iv, 1813, and vol. vi, 1815.

[2] Monro, collected works, 1725.

[3] Bell, 'System of Surgery,' 1787, vol. i, p. 61.

[4] Scarpa, 'Mem. sulla Legatura delle principali Arteri degli Arti, con append. sull' Aneurisma,' 1817.

day. By this method Scarpa and his followers obtained numerous successful results. In this country, however, Jones's views were already accepted, and consequently the Italian surgeon had scarcely any English adherents. But in 1821 Sir Charles Bell[1] published his work entitled 'The Great Operations of Surgery,' and in it directs that "the loop and knot of the ligature be sunk into the coats sufficiently to prevent the pulsation of the vessel shifting the ligature, but not drawn so tight as to cut the inner coats of the artery."

Many years before the discussion between the adherents of Jones and Scarpa (as to the best treatment of the wall of the artery) had become acute, the great advance of cutting ligatures short was attempted. This, it would appear, was first carried out by two assistant surgeons of the Royal Navy, Mr. Lancelot Haire[2] and another at the Haslar Hospital about the year 1780. To Lawrence[3] (1814) is due the development of this practice, which was not wholly satisfactory, for, as in Haire's cases, though the wounds healed by first intention yet subsequently the ligature almost always suppurated out. The next step was the trial by Astley Cooper[4] (1817) of catgut with the ends

[1] Bell, 'The Great Operations of Surgery,' 1821.

[2] Lancelot Haire, 'London Med. Journal,' vol. vii, 1786:—"An intimate friend of mine, a surgeon of great abilities, proposed to cut the ends of the ligatures close, and thus leave them to themselves. By following this plan we have seen stumps healed in the course of ten days. The short ligature, thus left in, commonly made its way out by a small opening, in a short time, without any trouble, or the patient being sensible of pain."

[3] 'Med.-Chir. Trans.,' vol. vi, 1814.

[4] *Catgut was first used on account of its absorbable qualities* by Sir A. Cooper. See 'Surgical Essays,' by Sir A. Cooper and Benj. Travers, vol. i, p. 125. A man, aged 80, with popliteal aneurism; ligature of femoral artery with catgut; ends cut short; wound healed by first intention in four days; patient up and about in three weeks. He remarks, "I confess that this case gave me much pleasure; the great age of the patient, the simplicity of the operation, the absence of constitutional irritation and consequently of danger, and his rapid recovery, lead me to hope that the operation for aneurism may become, at some future period, infinitely more simple than it has been rendered to the present moment" (ib., p. 129). Prof. Physick used buckskin in 1814 as an absorbable ligature.

cut short. He tried to get the ligature absorbed. His first case was a brilliant success, but his second case did not do well and he abandoned the practice. It is true that Galen[1] had long before recommended catgut, but he only did so if hemp or silk was not obtainable, and he says that the substance of the ligature should be such that it will not readily dissolve. To Lister[2] (1881) we are indebted for a method of preparing catgut which avoids the risk of its being absorbed too soon, and so makes it trustworthy.

The recognised practice at the present time may be said to be the use of the aseptic silk or catgut ligature so applied as to cut the coats of the vessel.

Lastly, it will be in the recollection of the Fellows that Mr. Barwell[3] (1879) has recently brought before the Society his plan of using tape-shaped animal ligatures for the ligation of arteries for the cure of aneurism. In his hands the practical application of this method has been most successful. Very recently Mr. Bennett May[4] has tied the innominate artery for subclavian aneurism with a ligature composed of six strands of catgut. The latter was

[1] Galen ('Methodus medendi,' liber xiii, ch. 22), speaking about bleeding, says, "But if, on laying bare the vessel, it should appear to you large, and to pulsate strongly, it is safer for the operator to put a (double) loop round it and to divide between; and let these ligatures be of a material that will not readily decompose. Such a material in Rome can be got from the Gaietans, who bring it from the country of the Kelts and sell it in the Via Sacra, which leads from the Temple of Roma to the markets. This is the easiest thing to get in Rome, for it is sold very cheaply there; but if you are practising your art in another city prepare for yourself some of the threads known as silk; rich women have these in many parts of the Roman empire, and especially in the large cities. If you cannot get this, choose the material least liable to decompose from among those that you can get where you are, such as fine catgut, for materials which easily decompose fall quickly out of the vessels, but we wish the knot only to fall out when the vessels have been well covered round with flesh, for the flesh which grows up in the parts of the vessels which has been cut off acts as a covering and stops its mouth, and when that has happened is the time for ligatures to separate without danger."

[2] 'Lancet, vol. i, 1881, p. 201.

[3] 'Med.-Chir. Trans.,' vol. lxii, 1879.

[4] 'Lancet,' vol. i, 1886, p. 1064.

drawn sufficiently tight to arrest all pulsation in the tumour, but not so tight as to impair the integrity of the arterial wall. There are few surgeons of the present day who practise the gentle treatment of the wall of the vessel, but to-night we desire to support their position from the experimental stand-point, and to recommend the employment of the small round absorbable ligature.

III.—*Opinion of the Present Day.*

The statement occurs or is implied in the language made use of in all recent text-books of surgery, that in the operation of ligature of an artery in its continuity the aim of the surgeon should be the complete division of the internal and middle coats of the vessel; and further, many and diverse ill results, such as hæmorrhage, or return of pulsation in the sac of the aneurism, are foretold as the probable consequence of any failure on the surgeon's part in carrying out this cardinal rule.

It is only necessary to refer to current surgical literature under the head of "Directions for the Operation," and whether the work of Bryant,[1] Erichsen,[2] Farabeuf,[3] Heineke,[4] Holmes,[5] or Mac Cormac[6] be consulted, the operator is told alike by each and all to tie the ligature strongly and steadily in order to divide the internal and middle arterial tunics. In most books, however, there is to be found evidence of considerable hesitation in the discussion of the subject. Heineke[4] is very uncertain, not knowing to which view to give the preference; he says, "It is only necessary that the artery be tied so tightly that the folds of the intima come in contact, but the ligature may

[1] 'Practice of Surgery,' 3rd edit., vol. i, p. 413.
[2] 'Science and Art of Surgery,' 9th edit., vol. i, p. 415.
[3] 'Manuel Opératoire,' 1881, pp. 24, 25.
[4] Billroth und Leücke, 'Deutsche Chirurgie,' Band 18, p. 94.
[5] Holmes, 'System of Surgery,' 3rd edit., vol. iii, p. 101.
[6] 'Surgical Operations,' Part I, 1885, page 19.

without disadvantage be drawn more tightly, in which case the inner coats are generally ruptured." Holmes and Erichsen give facts and arguments bearing on both aspects of the question. The former[1] says, "I have used Mr. Barwell's ligature myself with great success;" and again, "It is therefore probable enough that Mr. Barwell's view may be correct, but it cannot be said to be proved as yet, and I confess that I have always felt safer in drawing the ligature as tight as possible." Mr. Erichsen,[2] after mentioning the great danger of hæmorrhage subsequent to ligature of the first and second parts of the subclavian artery, concludes with the remark, "that the operation ought to be banished from surgical practice unless further experience shows that absorbable ligatures can be applied with certainty in such a way as to occlude the artery without division of its coats." Mr. Bryant[3] observes, when discussing the sloughing away of the portion of an artery included in a silk ligature, "that herein lies the weakness of the treatment by ligature." Lastly, Sir W. Mac Cormac[4] makes the following statements, which are germane to the object of this paper: "With some surgeons it is even now a question, as it was in Scarpa's day, whether or no it is desirable or necessary to divide by the ligature the internal and middle coats;" and again, "This practice has probably a better chance of success now than formerly as absorbable material is used."

IV.—*Authors' first Views.*

It is some years ago now that we first privately discussed the question of the ligature of an artery in continuity. The experiments of Scarpa and his contemporaries, and also those of the younger Cline and South[5]

[1] Loc. cit., 3rd edit., vol. iii, p. 101.

[2] Loc. cit., 9th edit., vol. ii, p. 201.

[3] Loc. cit., vol. i, p. 451.

[4] Loc. cit., p. 28.

[5] 'Chelius' Surgery,' translated by South, 1847, vol. ii, p. 221:—"A thread

(which show that by applying a ligature quite loosely around the carotid of a large dog the vessel becomes permanently occluded), seem to indicate that, by division of the coats of a vessel when not absolutely necessary to attain the end in view, surgeons are departing from that salutary law which precludes during operative measures any unnecessary injury to the tissues of the body. The evidence in this direction has gradually accumulated, and has led to the belief that the importance attached to damaging the arterial wall has been exaggerated and misstated, and that the operation of ligation in continuity ought to be reviewed in the light of recent advances in surgery and pathology.

V.—*Experimental Investigations.*

By the kind permission of Prof. Birch Hirschfeld and Dr. Hüber we put our views to the test of experiment in the pathological laboratory of the University of Leipzig. The experiments were made on sheep and horses, and we ligatured altogether sixteen carotids in sheep and three in horses. Strict antiseptic precautions were adopted; corrosive sublimate and carbolic acid being used for this purpose. The former answered best. The ligatures employed were kangaroo tendon from one twentieth to one twelfth of an inch in width, chromic catgut Nos. 3 and 4, and the green sulphurous catgut about No. 3 size. Except in Experiments 5, 6, 15, 16, 18 and 19 the ligature was drawn upon until pulsation on the distal side was arrested. The cavity of the artery is completely blocked in Specimens No. 15 and No. 19. It is much encroached upon in artery No. 18, but is scarcely involved at all in Specimens Nos. 5, 6, and 16. Excluding the above exceptions the

applied around the carotid artery of a dog so loose as not to interfere with the passage of the blood, is sufficient to cause inflammation, which will block it up completely, as was proved by an experiment made by my able master the younger Cline, and which I myself have repeated with the like result."

vessels were tied so that the lumina were nearly or wholly obliterated without any injury to the walls of the vessels. All the wounds in the sheep healed by first intention and remained aseptic throughout. Those in the horses suppurated more or less. The animals were killed at such periods as to allow of the vessels being removed at times varying from nine hours to seventy-three days. It will be observed that most of the vessels were removed from the bodies of the animals within three weeks. It was desired first to demonstrate the action of the small round ligature in occluding a vessel without damage to its wall, and to show that such an operation was easy and practicable. If a longer period had been selected it would have been difficult to convince everyone that the walls of the vessels were not ruptured, because the plastic process after a time obliterates the normal outline and the usual landmarks. Having proved the ease with which, by the small round ligature, ligation in continuity without rupture of the tunics can be done, we hope at some future time to make further experiments of a like kind, but with the arteries removed from the bodies of the animals at longer periods after ligature. Experiment 19 illustrates this point, but at present it stands alone. The carotid of a horse is seen permanently occluded on the fifty-first day.

Experiments 5, 6, and 16 taken together are very important. In No. 6 the artery is contracted and pervious after seventy-three days. In No. 5 (fifty-eight days) and in No. 6 (forty-four days) the vessels are filled with clot which is not adherent to the wall and which shows no evidence of organising changes. In each of these cases the vessel was scarcely, if at all, constricted by the ligature, and the tunica intima was thickened on account of its proximity to the clot. In all three a coagulum had formed which in one case had been washed away, whilst in the other two it would soon have met with the same fate. We can conclude therefore from these three experiments :—

That South and Cline were mistaken when they stated that an artery became permanently occluded by having a

ligature placed loosely around it; though a coagulum does form which lasts for about sixty days.

The kangaroo tendon was tied with the reef-knot, the catgut with the "double hitch" or surgical knot.

The majority of the vessels were immersed for preservation in equal parts of glycerine and absolute alcohol and brought to England for further examination, but some (six) were placed in carbolic solution (1-20). The alcohol caused the vessels to shrink to about a quarter of their original size.

Each vessel was split longitudinally through the middle of the knot of the ligature, so that the portion of the arterial wall subjacent to the knot and most exposed to injury comes well into view. One half was saved to be mounted as a naked-eye specimen in glycerine jelly, and the other part was reserved for the microscope.

We have much pleasure in thanking Mr. Horsley for his kindness in allowing us to use the Brown Institution for the purpose of working up our material.

VI.—*Specimens described and considered.*

Scheme of Experiments.—The following carotids of sheep were tied with kangaroo tendon. The ligature was applied except in the two cases mentioned below, so as to arrest the current of blood.

Exp. 1.—Carotid seven days after ligature. Lumen not quite obliterated. Commencing organisation of new material which is taking the place of the clot.

Exp. 2.—Carotid ten days after ligature. Lumen not quite obliterated. Organisation in clot more evident.

Exp. 3.—Vessel fourteen days after operation. Lumen occluded. Increasing development of new material in coagulum.

Exp. 4.—Vessel twenty-one days after operation. Lumen nearly occluded. Near the ligature the organisation of plastic material extends across the clot joining the opposite intimæ. (See Plate XI.)

Exp. 5.—Carotid fifty-eight days after operation. The ligature was placed loosely around the vessel without any attempt being made to control the passage of blood through it. The endothelial lining of the innermost coat is much thickened. The surface of the ligature is commencing to give way before the attack of the leucocytes. A clot fills the vessel which is not adherent, in which no organisation is taking place, and which would have been washed away in the blood stream if the animal had been allowed to live. This point is illustrated by the next experiment.

Exp. 6.—Carotid seventy-three days after ligature. As in the last case so in this, the ligature was applied around the vessel without any attempt being made to control the passage of blood through it. The ligature can still be seen with the naked eye. There is evidence that it slightly constricted the arterial wall. With the microscope its outline appears irregular; this is caused by absorption by the cellular invasion. In a very short time more, without doubt, it would have entirely disappeared. The vessel itself is contracted and diminished in size but pervious. The internal tunic is much thickened, especially the endothelial layer. It is certain that it was for some time obstructed by a coagulum which has been carried away by the blood stream.

The following carotids of sheep were tied with catgut, Macfarlan's No. 3 chromic catgut was employed except in the instances detailed. Each ligature (except in Experiments 15 and 16) was intentionally pulled upon until on its distal side the pulsation in the artery had ceased.

Exp. 7.—Vessel nine and a half hours after operation. Chromic catgut No. 4 was the ligature used. Lumen obliterated by the ligature.

Exp. 8.—Carotid twenty-four hours after operation. Green sulpho-chromic catgut No. 3 was used. Lumen occluded.

Exp. 9.—Vessel three days after operation. Calibre obliterated by the ligature.

Exp. 10.—Vessel seven days after operation. Lumen

not quite obliterated. Commencing organisation of clot near seat of ligature.

Exp. 11.—Vessel nine days after ligature. Lumen nearly occluded.

Exp. 12.—Vessel ten days after ligature. Calibre nearly obliterated.

Exp. 13.—Carotid fourteen days after operation. Calibre obliterated. Progressive organisation in clot.

Exp. 14.—Vessel twenty-one days after ligature. Calibre obliterated by ligature. Extensive organisation of plastic material in clot near the seat of ligation.

Exp. 15.—Vessel thirteen days after ligature. Complete obliteration by the ligature of the lumen of the vessel.

Exp. 16.—Vessel forty-four days after ligation. No attempt was made in this case to arrest by the ligature the passage of blood through the artery. A coagulum is present which is not adherent and which in the specimen has mostly fallen out. It shows no evidence of vital changes, and if the animal had been allowed to live would without doubt have been carried away in the blood stream. The tunica intima is much thickened. The catgut ligature is still holding its own. It must have been exceptionally well prepared to resist absorption for so long. The leucocytes, however, are working their way in from the surface, but yet the ligature would probably have remained unabsorbed for another fortnight if the sheep had been allowed to live.

The following carotids of horses were ligatured:

Exp. 17.—Vessel ten and a half days after ligature with kangaroo tendon. Lumen not quite obliterated. Commencing organisation in clot at the seat of ligation.

Exp. 18.—Carotid fourteen days after operation. Catgut Macfarlan's No. 3 was used. No attempt was made to completely arrest the flow of blood at the ligatured point. The lumen is encroached upon but not nearly obliterated by the ligature. In the specimen the clot has dropped out except at the point of ligation. Much sup-

puration took place, hence the great amount of plastic exudation. The ligature is being rapidly absorbed.

Exp. 19.—Carotid fifty-one days after operation. Chromic catgut No. 3 was the ligature used. The calibre at the ligatured point was evidently not quite obliterated. Organisation in the clot in the neighbourhood of the ligature is complete, for a fibrous union extends across the interval which had previously been occupied by coagulum from the inner coat of one side to the inner coat of the opposite side. The ligature is absorbed. No trace of it is visible.

The macroscopic[1] and microscopic examination of the specimens show :

1. That in no instance were the arterial coats injured by the ligature.

2. That except in three cases (Experiments 5, 6, and 16), in which the arteries were only slightly constricted, the lumina of the vessels were either wholly or nearly occluded. In other words, at the point of ligature either the internal coat of one side was in apposition with the internal coat of the opposite side, or a thin strand of clot blocked the lumen of the tube at the point of constriction and was continuous with the main body of the clot both above and below.

3. That external to the artery, surrounding the ligature and extending a short distance on either side of it, was a small amount of constructive exudation-material, due to the presence of the ligature and the disturbance of parts which was a necessary coincidence of the operation. When suppuration took place, as in Experiment 18, the amount of plastic exudation thrown out was much greater.

4. That the ligature, whether of tendon or catgut, to the naked eye is practically unaltered, is not producing any irritation, and is holding well at the end of twenty-one

[1] The macroscopic specimens are preserved in the museum of the Royal College of Surgeons.

days. In Experiment 19, fifty-one days after operation, the catgut ligature has disappeared. In Experiment 6, seventy-three days after operation, the tendon ligature is almost entirely dissolved.

5. The gradual diminution and contraction of the vessel, which was most marked on the proximal side of the ligature. (Those arteries which were taken from the bodies of the animals twenty-one days after operation, were discovered by measurements taken immediately after death to have shrunk to less than half their diameters at the time of ligature.)

6. The decolorisation and absorption of the clot and the organisation of plastic material which is taking its place, is well seen in the neighbourhood of the ligature when the latter wholly or nearly obstructs the cavity of the vessel, and in three weeks by this process the proliferating endothelium of one side is in vital union with the proliferating intima of the opposite side—the clot space being thus rapidly bridged across. When the vessel is only slightly constricted a coagulum forms but it remains a "foreign body" destitute of vital action until it is carried away by the blood-stream.

7. A careful investigation of this series of experiments demonstrates clearly—

1. That when an artery is only slightly constricted it becomes temporarily blocked for a considerable time—from fifty to seventy days. It then, much diminished in size, resumes its function as a carrier of blood.

2. That when an artery is wholly or nearly occluded by the ligature, plastic processes (which can be readily traced from their commencement a few hours after ligation to their completion fifty days later in the microscopic sections) supervene which permanently block the lumen of the vessel, which unite the inner coats of opposite sides and which practically finally convert the artery at the seat of ligature into a solid fibrous band.

VII. *The Coagulum.*

The clot which forms above and below the seat of ligature is not in any sense a necessary part of the process by which an artery is obliterated. Ziegler,[1] Cornil and Ranvier[2] and others[3] have advocated this view. Travers[4] experimentally proved its non-essential nature though many before his day had combatted the doctrine of Petit.[5] The coagulum within a deligated vessel is as much a foreign and dead substance as the clot on the flap of an amputation stump. It, like the aseptic animal ligature encircling the artery, is gradually absorbed. Its function is to act as a barrier or buffer between the impulse of the blood-stream and the seat of ligature where the important plastic actions are in progress which might otherwise be disturbed or interrupted ; and also, perhaps, in the vicinity of the ligatured point to afford some support—ladder-like —to the plastic[6] effusion as the latter climbs across the cavity of the vessel. Whether the tunics be ruptured or not, the coagulum takes no part in the adhesive process by which the final occlusion of the vessel is secured, but upon its deficient formation, when the arterial wall is damaged, may depend an attack of secondary hæmorrhage, especially if a large collateral branch be close to the deligated point. The adhesive changes only involve the clot in the immediate neighbourhood of the ligature. The remainder of the clot, which is the greater part, after some time disappears and its place is occupied with fluid blood again. These changes always end in a permanent diminution of

[1] Ziegler, 'Pathological Anatomy,' pt. 2, par. 255.

[2] Cornil et Ranvier, 'Manuel d'Histol. Pathol.,' 1881, vol. i, p. 601.

[3] Spence, 'Lectures on Surgery,' p. 515; Farabeuf, 'Manuel Opératoire,' 1881, p. 28.

[4] Loc. cit.

[5] Petit (1710) was the first to conduct experiments on the ligature of arteries. He thought the coagulum was the chief factor in the arrestment of hæmorrhage and the process of obliteration.

[6] John Bell, 'Principles of Surgery,' 1801, vol. i; Jones, loc. cit., p. 160.

the calibre of the vessel above and below the ligatured point.

Our specimens illustrate these views. In each case in which the vessel cavity was entirely or almost entirely obliterated by the ligature, the microscope shows that a cellular infiltration is taking place into the wall of the vessel around the ligature and into the clot. The longer the interval which elapsed between ligation and the death of the animal so much the more organised is the plastic effusion. By means of these cells the clot near the ligature is decolorised and with the ligature is at last completely absorbed. Vessels developed from the formative material which is taking the place of the clot are to be seen at the end of a fortnight or three weeks passing across from the proliferating intima, or plastic effusion, within the intima of one side to the intima of the opposite side. In other words the inner coats of opposite walls are commencing to be adherent. Already there is a living connection, and the intervening space is filled with a tissue which only requires a short time more for its perfect development.

The same adherent changes are evident in the thin strand of clot, which in some instances is visible at the point of ligation, as are seen in the main body of the clot just above and below the ligature when the lumen of the vessel is obliterated. In those sections in which the tunica intima of one side is shown approximated to the tunica intima of the other, there is a direct vital adherence without the assistance of any intervening material, but dependent upon, as in the former case, the plastic cellular extravasation. This is of the utmost importance, for it proves that it is of comparatively little moment whether the ligature which does not damage the coats completely or almost completely closes the lumen of the vessel. In Experiment 19 the carotid of a horse which was not completely closed by the ligature is converted at the seat of constriction into a solid fibrous band.

Reidel[1] is said to have made the inner surfaces of an

[1] Quoted by Ziegler, 'Pathol. Anat.' (Eng. trans.), vol. ii, p. 14.

artery cohere by multiplication of the opposed endothelial cells without the formation of clot. Of the accuracy of this observation we have grave doubts. Any alteration in the endothelial lining would certainly lead to the formation of a coagulum, and the endothelial multiplication in our specimens is always accompanied by a leucocytic extravasation, the latter apparently being of more importance than the former. A long time after ligation the clot disappears and leaves the interior of the vessel—on either side of the ligatured point—in shape something like a hollow cone. This may possibly be the explanation of the statement of Reidel.

The time at which the clotting took place in these experiments is a matter of doubt, but it probably supervened soon after the operations were over. The shortest time which elapsed between ligation and the death of an animal was nine hours. Here the clot was perfectly formed. When the coats are ruptured the clotting commences at once on the infolded edges of the cut tunics, but in these arteries no such cause was present and the development of the coagulum must be attributed, not to the stasis of the blood current, but to the change in the vital state of the arterial wall due to the pouring out of lymph at the point of ligature.

VIII.—*The Ligature.*

Experiments upon arteries in the post-mortem room show :

1. That the effects produced by the use of a silk or other ligature applied in the ordinary way are not uniform. The middle coat is sometimes only partly cut through but in other instances a mere strand of tissue representing the outer coat alone remains, which remnant is thinnest and quite transparent under the knot of the ligature. Here then is ample reason for the occasional occurrence of

hæmorrhage; for not only is the wall of the vessel nearly divided at every point but in the knot region the outer tunic has almost given way. During last autumn the opportunity was afforded of dissecting a case in which secondary hæmorrhage, preceded by some suppuration, occurred after ligature of the carotid. The wall of the vessel had given way at its weakened and most disabled point, *i. e.* nearest the skin under the knot.

2. That there is no difficulty in tying an artery with a small round ligature sufficiently tight to make it impermeable to water without the least damage to the coats. The occlusion is caused by a longitudinal wrinkling of the wall.

3. That a tape-shaped animal ligature a quarter of an inch in width will rupture the coats of an artery if force be used. The knot of such a ligature is clumsy and the tape does not lie flat in the neighbourhood of the knot.

The choice of material for the ligature has been much debated.

1. It is not easy to make silk aseptic. This is probably on account of the presence of recesses in which bacteria can lodge. When employed outside the peritoneum there is some uncertainty as to what will happen to it. It may become encysted or it may ulcerate out. The question in the past has been one of gangrene at the seat of ligature and of inflammation on either side; now suppuration in such a wound is and ought to be the exception. Senn[1] has shown that a silk ligature applied to an artery in its continuity without damaging the tunics always cuts its way through the vessel and frequently becomes encysted by the side of it. Dr. Kölliker, of Leipzig, informed us that of eighty amputations antiseptically performed in which he had carefully searched for the silk ligature used for the main vessel, he had only succeeded in finding it in about one third of the cases. He supposed that some of the ligatures had escaped his observation and that it was fair to estimate that one half remained encapsuled in

[1] 'Trans. Amer. Surg. Assoc.,' vol. ii, 1885, p. 345.

the stumps and one half came away in the discharges. Silk[1] then hardly fulfils our ideal of a perfect ligature for aseptic wounds.

2. Of late years catgut has been extensively used. Lister[2] lays stress upon its preparation, specially insisting upon the scraping off of the mucous and peritoneal surfaces of the bowel from which it is made; and upon the fact that it is absorbed from the surface. Our microscopic preparations demonstrate, however, that our catgut had not had the mucous coat removed for villi and mucous follicles are to be seen. To the naked eye there is no change visible even at the end of twenty-one days. With the microscope at the end of the third day the dendritiform arrangement of villi and mucous follicles can be easily made out following certain wavy lines which cross the section of the catgut. On the seventh day after ligature this appearance is not nearly so clearly defined, and there are some cracks or splits running from the surface towards the centre. Along these splits leucocytes are gathering. Fourteen days after operation the dendritiform picture has disappeared and the cracks are wider and deeper; and at the end of twenty-one days the fissures are still more marked and the circumference of the catgut and the sides of the cracks bear evidence at several points of the eroding and absorbing influence of the surrounding leucocytes. (Plate XIII.)

In Experiment 18, in which profuse suppuration followed the ligature of the carotid of a horse, the ligature—catgut—is breaking up rapidly at the end of fourteen days. In Experiment 19, in which the vessel was removed fifty-one days after operation, there is no trace of the ligature. In the microscopic sections of artery No. 16 the catgut, which is apparently exceptionally good, is holding well after forty-four days. We think that well prepared chromic catgut will last for one month or more; and, as a ligature upon an artery in continuity, will not give

[1] Holmes, 'Surgery, its Principles and Practice,' p. 94.

[2] Loc. cit.

way in a less time unless very profuse suppuration occur.

3. The tendon used by us has several points in its favour:

a. The structure is continuous throughout, and there are no spaces as there are in catgut, due to twisting in its preparation.

b. It does not split or crack during absorption, which takes place "from the surface."

c. It is easily made aseptic.

d. It is only gradually, and after a long time, acted upon by the living materials which encompass it.

Kangaroo tendon is very convenient for practical use, being strong, of ample length, and becomes as supple as silk by soaking for half an hour in tepid sublimate solution.

The tendon ligature shows scarcely any absorption on the surface at the end of twenty-one days. Leucocytes are collecting, as in the catgut specimens, in a dense mass on the outer side. In Experiment No. 5 the tendon is seen fifty-eight days after operation and does not exhibit much change except on the surface microscopically. In Specimen No. 6 the tendon seventy-three days after ligature shows unmistakeable signs of disappearance. The circumference is deeply indented and wavy in outline.

We consider that kangaroo tendon ligature may be looked upon as trustworthy for at least two months.

IX. *Objections discussed.*

The following are some of the objections which may be raised:

1. *That conclusions based upon the ligature of the carotids of sheep, and which are intended to be a guide to practice, are founded upon an analogy which is not wholly supported by the facts,* because:

A. The circulation in sheep and other herbivora is not so vigorous as in man.[1]

B. The carotid of a sheep is not quite so large as a human carotid.

To meet this objection the carotid artery of the horse was ligatured in three instances. This vessel is much larger and the blood pressure is much greater than in the corresponding artery of man. The macroscopic and microscopic preparations of these three horse carotids show exactly the same changes as are seen in the ligatured carotids of sheep; and in Experiment 19 the carotid of a horse at the end of the fifty-first day is converted at the ligatured point into a solid fibrous mass.

2. *That it does not matter under the Listerian system whether the tunics be ruptured or not; that there is no danger involved in the division of the coats, and that the result cannot be (with primary union of the wound) disastrous to the patient.*

There can be no dispute about the supreme desirability of obtaining perfect asepsis, but to the belief as stated above we cannot subscribe, because:

A. It is not justifiable to do more than is absolutely necessary to attain the end in view.

B. It cannot be expected that wounds will always heal by first intention and remain aseptic throughout. Though most cases of ligature of arteries in their continuity with strict antiseptic precautions are successful, it is not well

[1] The relative blood-pressure in the carotid of man, compared with that in the same vessel of other large mammals, is as follows:

Horse	160—220 mm. of mercury.
Sheep	155—210 mm. „
Man	150—200 mm. „
Large dog	140—180 mm. „

From private letter (Mr. Langley, of Cambridge).

The relative size of the dead carotid of man, compared with the same vessel of the horse and sheep, is as follows:

	Outside diameter.	Inside diameter.	Thickness of coat.
Horse . .	12 mm. ...	9 mm. ...	1½ mm.
Man . . .	7 mm. ...	5 mm. ...	1 mm.
Sheep . .	5½ mm. ...	4 mm. ...	¾ mm.

to trust too much to asepsis. It has already been shown what may happen if asepsis be not perfect.

The minimum of unsuccessful cases may probably be greatly reduced by the employment of means which, while efficiently occluding the vessel, do not at the most critical moment, and at the situation of greatest strain, destroy the strength of the arterial wall.

3. *That it is more difficult to tie a vessel without damaging its coats than to tie it in the ordinary way.*—To this statement a denial must be given, for we are sure from experiments upon dead arteries that it is just as easy to learn thus to tie an artery as to ligature one by main force.[1] It is always possible to tell at once when the ligature must not be drawn any tighter, for a certain resistance is felt by the fingers which, if overcome, is overcome suddenly and with a snap, and means the giving way of the two inner coats of the vessel; and further, the cessation of pulsation in the artery or its branches beyond the ligatured point, or in the case of aneurism the cessation of pulsation of the tumour, is an important indication to the operator to abstain from tightening much more the knot of the ligature.

4. *That it is not easy perfectly to occlude an artery without rupturing its coats.*—This, however, is not the fact. It is quite easy in the post-mortem room to tie an artery with an ordinary silk ligature without any damage to the tunics and yet so completely to occlude the vessel as to prevent the passage of any water even when the latter is forced in by means of a syringe. The specimens show moreover that it is not necessary that the tunica intima of one side should be in apposition with the tunica intima of the opposite side, though in some instances this perfect approximation does obtain. Supposing the lumen of the artery not to be completely closed by the ligature and a small space to remain through which blood could find its way in small quantity, clotting must inevitably soon take place. But even if coagulation were delayed for some

[1] Farabeuf, loc. cit., p. 26.

hours the trickling of a little blood through the vessel at the ligatured point would be by no means disadvantageous from the point of view of the formation of a firm clot in the sac of the aneurism.

5. *That the ligature may rapidly dissolve so that the circulation through the vessel becomes quickly re-established.*—This has happened in actual practice[1] with carbolic catgut. Such a result is not surprising, considering that ligatures of badly prepared catgut may separate and be found in the discharges thirty-six or forty-eight hours after an operation.

Our specimens show that properly prepared chromic catgut or kangaroo tendon possesses great powers of resistance to the action of living tissues and prove therefore that with well-selected materials an untoward event of this sort could not happen.

6. *That the vessels may become pervious after a more or less lengthened period by absorption of the ligature and canalisation of the clot or new material at the point of ligature.*—To this objection it may be urged:

A. That aseptic ligatures can only be absorbed or encapsuled. That the former would certainly have happened in our cases but that the materials used would have been entirely absorbed, only after some months when all surrounding parts would have changed into fibrous tissue.

B. That though a clot, when it remains at the point of ligature simply as a lifeless mass (as in those instances in which the arterial wall is only slightly constricted) must be ultimately carried away in the blood stream, yet when organisation does occur to the extent of bridging over the interval occupied by the coagulum, it must continue until the "new material" is changed into a permanent fibrous mass.

C. That granting for the sake of argument that the circulation would be re-established in some modified degree, it is obvious that such an event could not occur

[1] Bryant, 'Surgery,' 3rd edit., vol i, p. 414; Treves 'Brit. Med. Journ.,' vol. i, 1881, p. 232.

except after the lapse of many weeks, and that supposing *e. g.* that the operation was performed for the cure of aneurism, the re-establishment of the circulation would be heralded long before by the effectual cure of the disease as far as the cure was dependent upon the passage of blood through the vessel tied.

7. *That if suppuration occur in the wound the patient would be placed in a position of greater danger than if the arterial wall had been dealt with in the usual way.*—We are, however, convinced from the study of the history of ligature before and since the antiseptic era, that the danger to the patient is greatly augmented by the division of the two internal layers of the arterial wall. We have dissected a case in which the popliteal artery passed safely through the centre of a large abscess cavity, suffering only a slight thickening of its sheath and outer coat, and had there been any artificial injury to the barrier of the arterial wall the chances of a disastrous termination from hæmorrhage would have been very much magnified. In St. Thomas's Hospital museum are the carotids of horses tied with rupture of the tunics by Travers. In several of these cases severe secondary hæmorrhage occurred, in one case to syncope. On looking at our three specimens it will be seen that hæmorrhage could not occur, for the vessel wall in each case is intact, though suppuration supervened, and in Experiment 18 was most profuse. The strongest section of the arterial wall, when the coats are uninjured, is at that point where it is strengthened by a scaffolding of ligature plus the sheath of plastic exudation material which is rapidly developed into young fibrous tissue.

8. *That*[1] *plastic lymph is effused as a consequence of the injury done to the coats, and upon the amount and vitality of the effusion depends the safe closure of the vessel. That*[2] *the injury done to the intima is of cardinal importance for the formation of thrombus and the development of adhesive*

[1] Mac Cormac, loc. cit., p. 25.

[2] Ib., p. 29.

inflammation. That[1] *if these coats are not lacerated it is probable that no lymph will unite their opposed surfaces.*— The naked-eye and microscopic preparations of the vessels in our experiments, however, show an effusion of lymph which is ample for the purpose in view, viz. the occlusion of the vessel, so that the plastic exudation cannot be said to be dependent in quality, though possibly in quantity, upon rupture of the tunics.

9. A.—*That when two endothelial surfaces are brought into contact they unite with difficulty, and that therefore it is necessary to interrupt the continuity of the tunics.*

B.—*That it is an advantage to bring, by means of the cutting ligature, the adventitia of one side into close relation with that of the opposite side, because union between areolar structures is rapidly effected.*

Our preparations clearly demonstrate that these are theoretical issues having no foundation, and that union is obtained as firmly and as rapidly, and more safely, when the tunics are undamaged than when they are divided. Other endothelial surfaces when in contact are known to adhere on the least provocation. Ziegler[2] says "that a blood-vessel has an anatomical analogy to the serous cavities" and that "the process by which a thrombus is organised resembles most closely the plastic inflammation of a serous membrane." The presence of a ligature even when loosely applied round an artery is sufficient to cause a slight deviation from the normal nutrition of the part, accompanied by plastic effusion, proliferation of the endothelium, and coagulation of the blood.

Ziegler figures an organising thrombus from the femoral artery of an old man. The tunics had been ruptured and the examination was made three weeks after ligature. Let this picture be compared with the process as seen in a sheep's carotid twenty-one days after operation without division of the coats. In the latter case the process of organisation is much more advanced than in the former,

[1] Holmes's 'System of Surgery,' 3rd edit., vol. iii, p. 101.

[2] Loc. cit., p. 11.

for in the human femoral the blood-cells of the clot are visible and the large fusiform and ramified cells are only beginning to be formed near the endothelium and to extend inwards between the cells of the coagulum ; but in the sheep's carotid a network of these formative cells has already extended from the inner tunic of one side across the clot to the inner tunic of the opposite side, and the individual cells of the coagulum cannot be distinguished. In other words, the constructive process as seen in the plastic effusion, proliferation of the endothelium and disappearance and absorption of the blood-cells and fibrin of the clot may be said to progress at any rate as rapidly when the integrity of the arterial wall is secured as when it is destroyed.

X. *Conclusions.*

The conclusions at which we have arrived may be briefly stated as follows :—

1. That the operation of ligature of a large artery in its continuity should be performed without damage to its wall.

2. That the rupture of the coats of an artery during ligation in continuity is a useless and dangerous proceeding. Useless because the surgeon can secure the effectual attainment of his object, viz. the occlusion of the vessel, by a measure at once safer and less severe ; and dangerous on account of the possible occurrence of some untoward event, such as hæmorrhage or secondary aneurism at the seat of ligature, which could not happen if the wall of the vessel were uninjured by the ligature.

3. That if the wall of the artery be diseased, the advantages attending ligation without rupture of the tunics are much magnified. It sometimes happens that the surgeon on cutting down upon a large artery observes a state of atheroma so extensive that he is obliged to close the wound and ligate a vessel nearer the heart and thus expose his patient to considerably increased risk. There is no escape from such a dilemma under the system which

declares that the arterial coats must be divided; but with a non-irritating aseptic ligature so applied as not to lessen the power of the arterial wall but actually to be a source of additional strength to it where it is most desirable to conserve this quality, the question of ligation is seen under entirely new auspices, and the occlusion of a diseased artery would be undertaken with an assurance of success almost equal to that which obtains when a healthy vessel is in question.

4. That when the coats of an artery are uninjured by the ligature, the danger of ligation near a large collateral branch is wholly avoided, because—

A. No danger can accrue from hæmorrhage when the wall of the vessel is intact.

B. The formation of clot upon which the safety of the patient so much depends, if the wall of the vessel be damaged, has really nothing to do with the adhesive changes which take place in a ligatured vessel.

C. The plastic actions which proceed at the place of ligation are practically alike whether the tunics be ruptured or not. In the former case, however, any retardation of the constructive process, especially when in the vicinity of a large collateral branch (on account of the general condition of the patient or from accidental slight septicity of the wound) may be attended with grave risk to life—a risk which can by no means be made light of even when the course of events in the wound is apparently favorable. On the other hand when the tunics are undamaged the nearness of a collateral branch and suppuration in the wound are comparatively immaterial, and the reparative and adhesive efforts of nature as seen in the effusion and organisation of lymph develop, even when delayed, an additional stay to the unweakened and living arterial wall.

5. That the ligatures employed in this series of experiments were probably in all cases larger than was absolutely necessary to secure the obliteration of the vessels to which they were applied. Comparatively speaking they were not large. It would appear that a small round

aseptic ligature which will not become absorbed in a less time than three weeks, and which during that period holds firmly so as to cause a constriction of the arterial wall, and complete or almost complete obstruction of the cavity of the vessel will so influence the nutrition of the part that permanent occlusion will follow.

6. That it is no more necessary to use a flat tape-shaped ligature (as recently revived by Mr. Barwell for the purpose of preventing damage occurring to the arterial wall during ligation) than to rupture the coats of the vessel. The small round ligature is the most easy to manipulate, and it is not difficult to learn to apply it in the manner here indicated.

7. That the essentials to be observed in the ligature of arteries in their continuity are :

A. Complete antiseptic precautions to ensure the primary union of the wound.

B. A non-irritating aseptic ligature such as kangaroo tendon or chromic catgut, which will remain for a considerable period without becoming appreciably altered by the temperature and tissue environment of the living body.

C. The application of the ligature so as to close or almost close the lumen of the vessel without causing the least injury to the arterial wall.

The sum up, we venture, though fully conscious of the incompleteness of the experimental proof which is placed before the Society to-night, to advocate—

1st. The use of antiseptic precautions.

2nd. The employment of the small round absorbable ligature.

3rd. The maintenance of the integrity of the arterial wall.

(For report of the discussion on this paper, see 'Proceedings of the Royal Medical and Chirurgical Society,' New Series, vol. ii p. 112).

DESCRIPTION OF PLATES XI, XII, AND XIII.

The Ligation of the Larger Arteries in their continuity: an Experimental Inquiry, by CHARLES A. BALLANCE, M.S., and WALTER EDMUNDS, M.C.)

PLATE XI.

The carotid of a sheep twenty-one days after being ligatured with kangaroo tendon.

FIG. 1.—Under low power, showing that the wall of the vessel is uninjured. The spot from which the high power drawing (fig. 2) was taken is marked by lines.

FIG. 2.—Section taken through the clot from one side of the vessel to the other in the immediate neighbourhood of the ligature. The cellular invasion and the proliferating endothelium are well seen. The blood-cells of the coagulum have become indistinguishable. The new material which is absorbing the clot, and taking its place, is already so far developed as to form a vital connection between the intimæ of opposite sides.

PLATE XII.

Carotid of a horse fifty-one days after being ligatured with chromic catgut.

FIG. 1.—The lumen of the vessel was, as far as can be made out, not quite obliterated by the ligature. There is no trace of the catgut to be discovered, even with the microscope. The place of the clot is taken by connective-tissue material, which has completely fused with the intimæ of opposite sides. Spot from which high power drawing (fig. 2) was taken is marked by lines. *Probable position of ligature.

FIG. 2.—High power drawing of part enclosed by lines in fig. 1. Complete fibrillation of new material which is taking the place of the clot, and fusion of new material with the wall of the vessel on either side. The organisation is more advanced nearer the ligature.

PLATE XIII.

FIG. 1.—Chromic catgut (No. 3) removed from a sheep three days after being used for tying the carotid. A dense mass of leucocytes is collecting on the outer side of the ligature. The mucous coat has not been removed in the manufacture of the ligature. The intestinal villi and crypts are clearly visible.

FIG. 2.—Showing rapid destruction of chromic catgut used for the ligation of the carotid of a horse fourteen days previously.

FIG. 3.—Chromic catgut ligature forty-four days after being employed for ligaturing a sheep's carotid. It is still holding, and likely to last for some time longer. This piece of catgut is exceptionally good; it was probably prepared with care.

FIG. 4.—The remains of a kangaroo tendon ligature seventy-three days after ligation of a sheep's carotid.

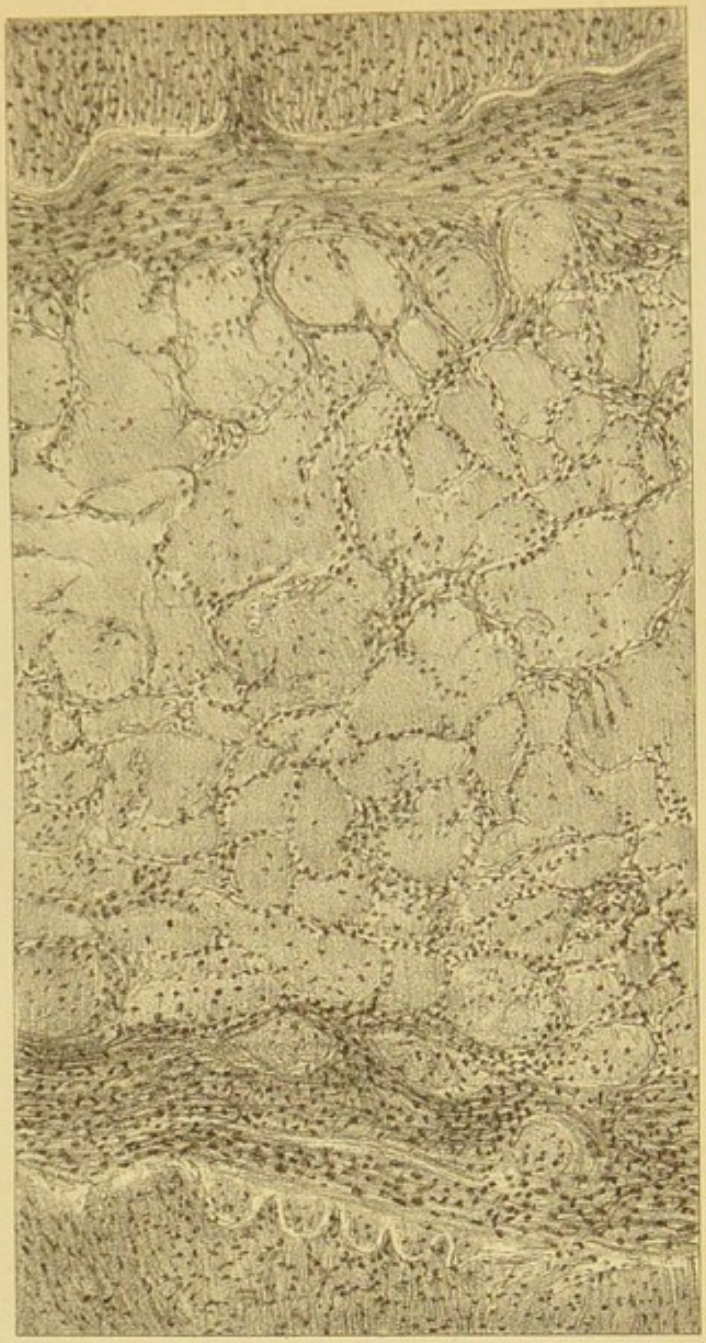

Fig. 2.

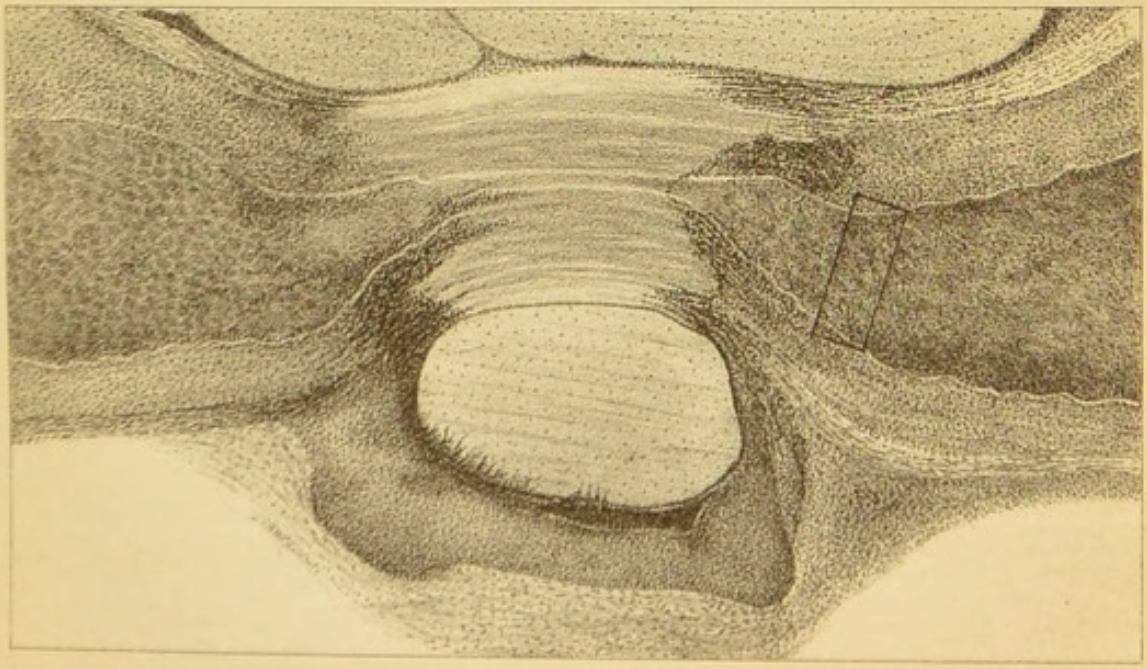

Fig. 1.

Mintern Bros. lith.

Fig. 1.

Fig. 2.

Mintern Bros. lith.

Fig. 1.

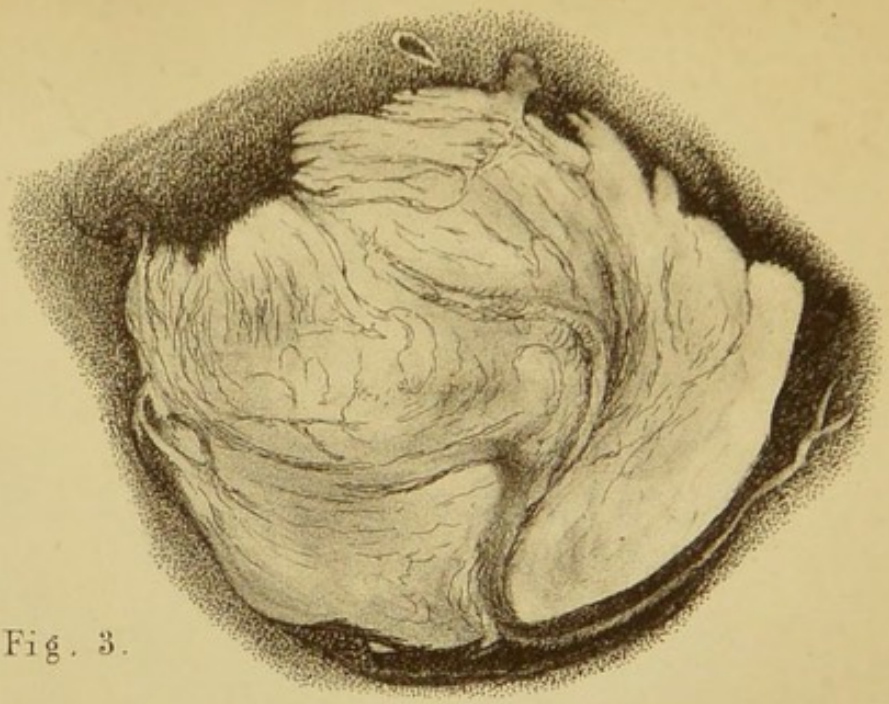

Fig. 3.

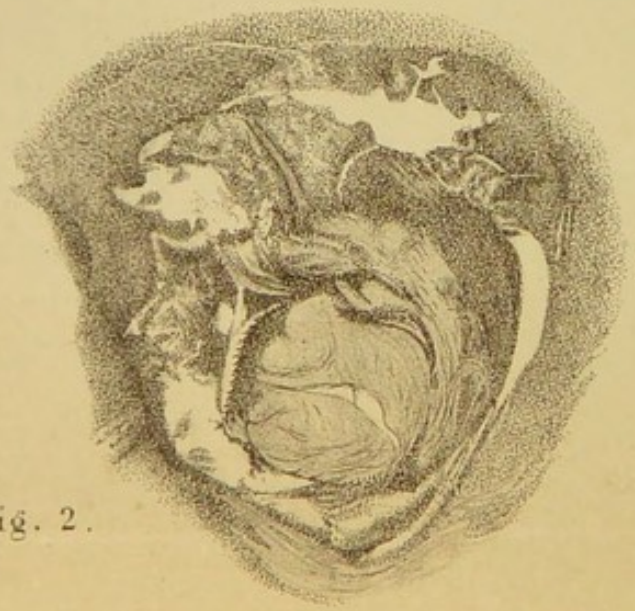

Fig. 2.

Fig. 4.

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