

The sphygmograph and the physiology of the circulation : a monograph read before the Medical Society of New Jersey, upon investigations made preparatory to a larger work on the practical value of the sphygmograph / by Edgar Holden.

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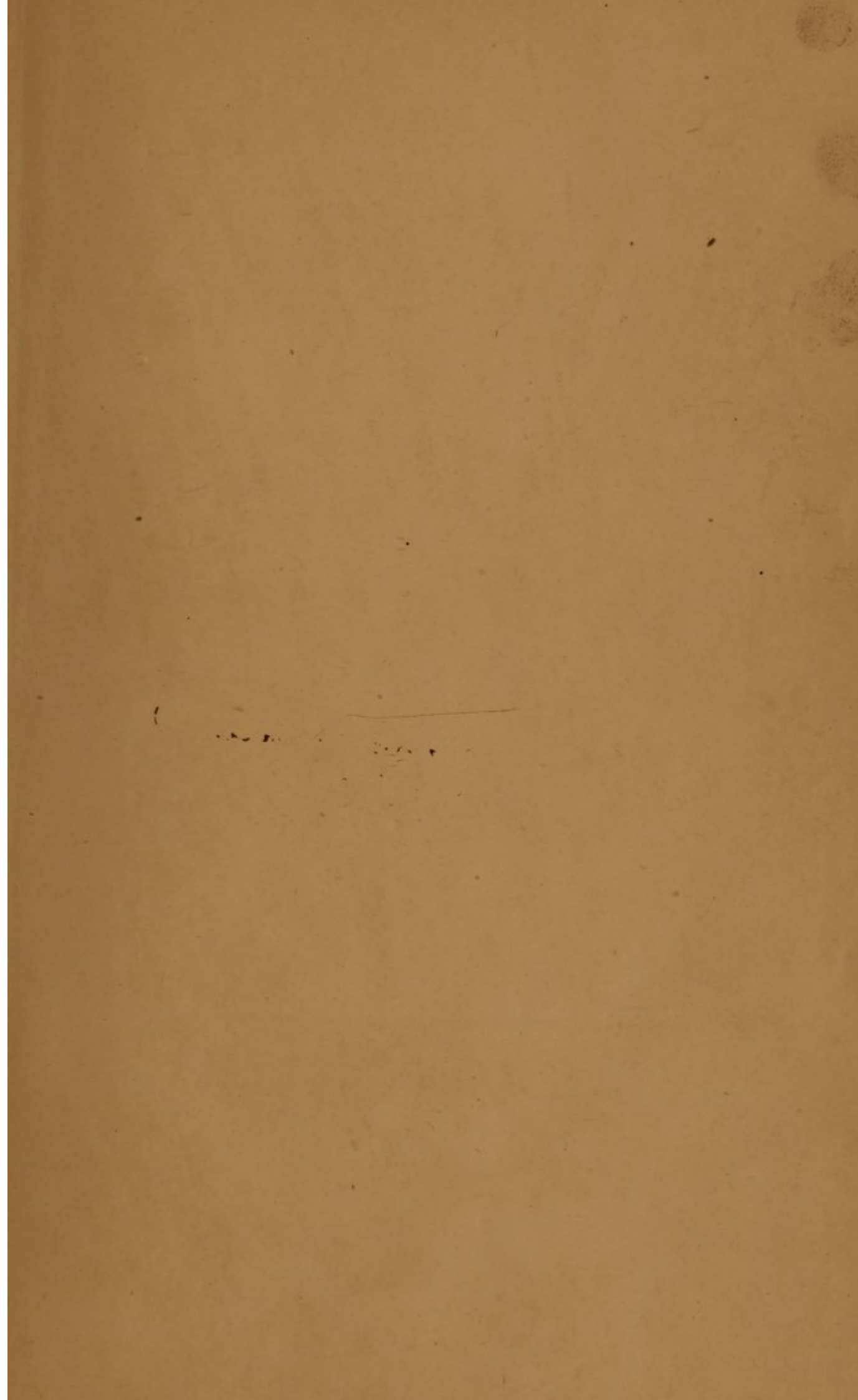
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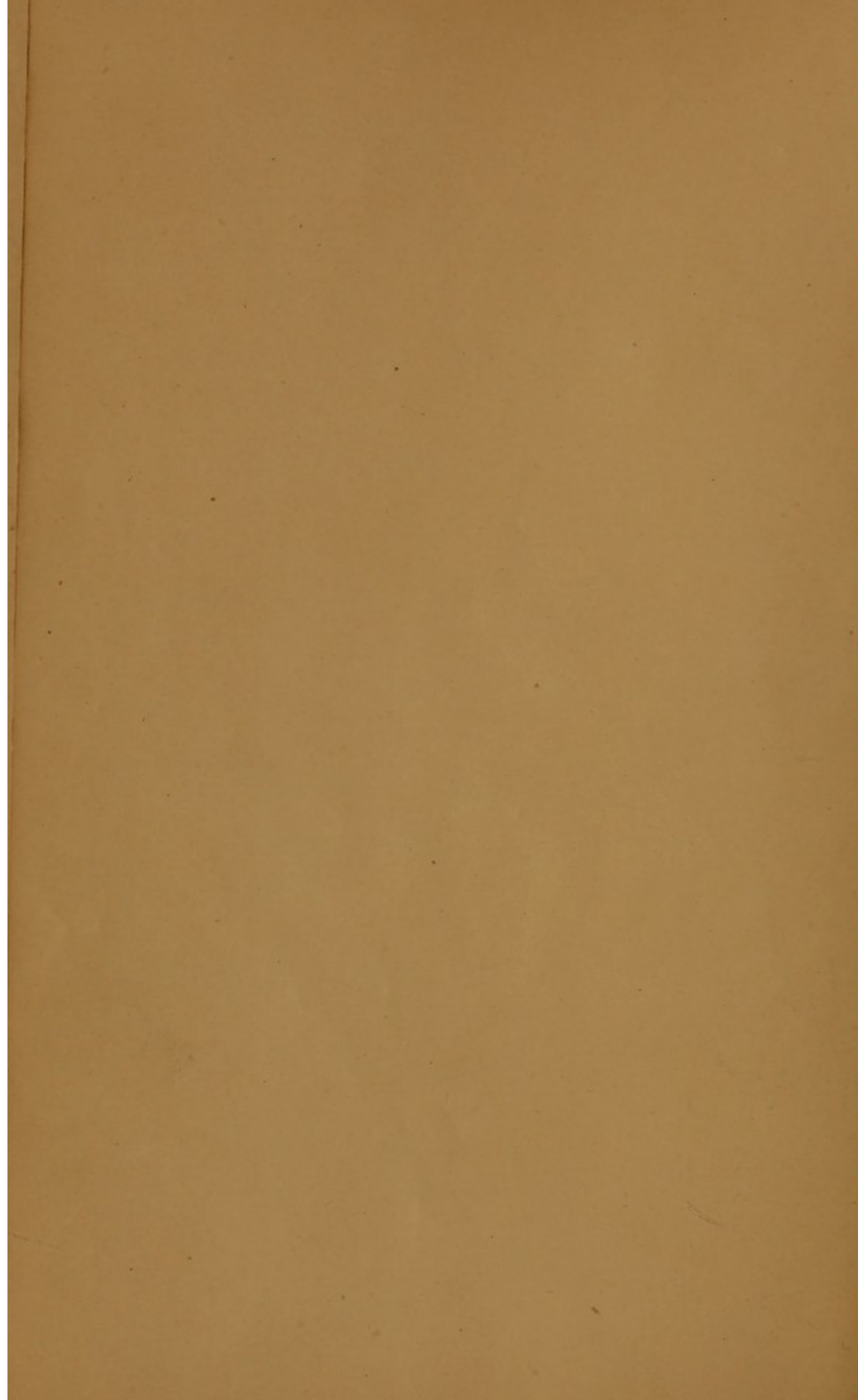
THE SPHYGMOGRAPH.

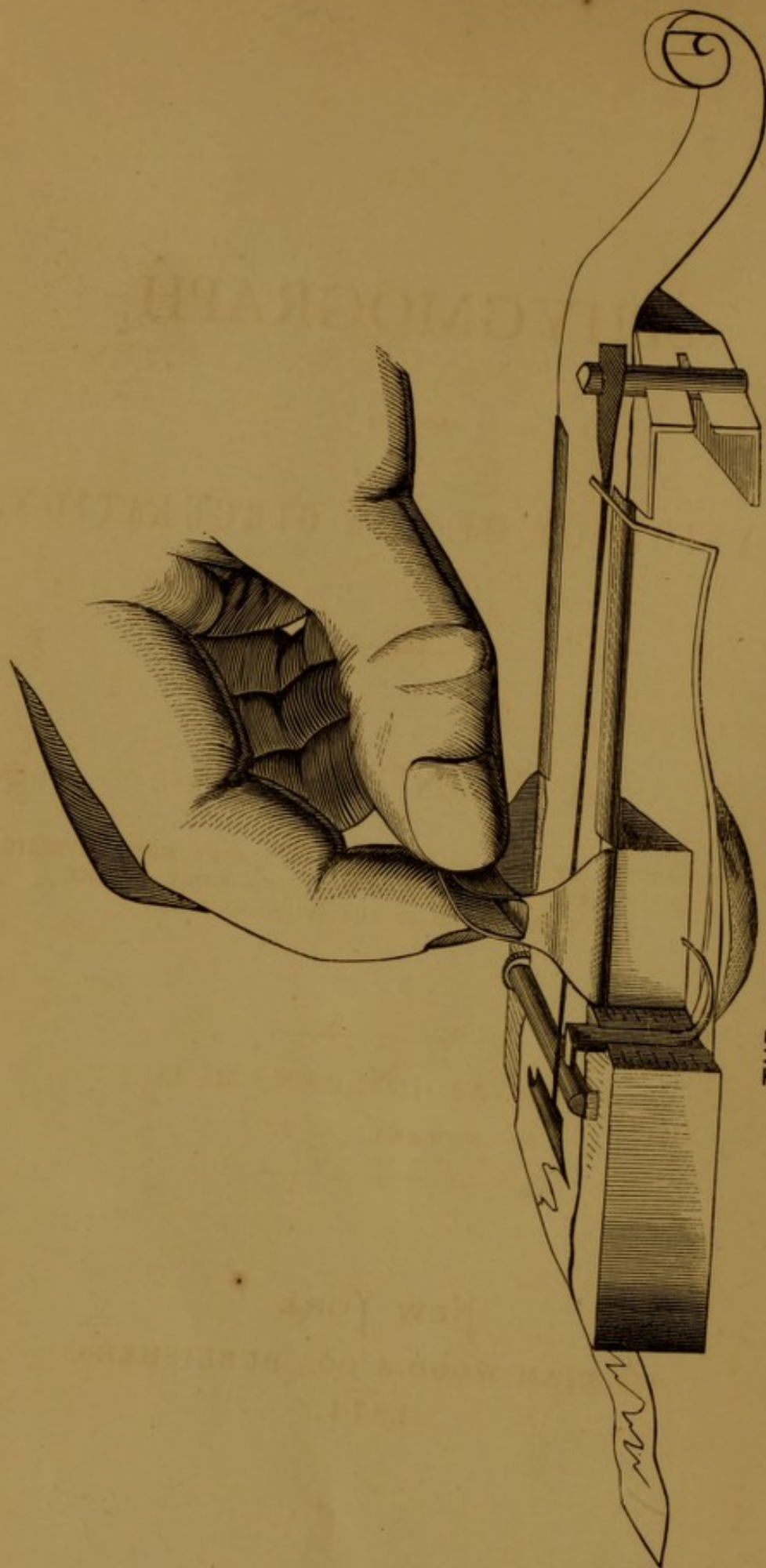
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THE NEW SPHYGMOGRAPH—FULL SIZE.

Compliment of Author

THE
SPHYGMOGRAPH
AND THE
PHYSIOLOGY OF THE CIRCULATION.



A MONOGRAPH

READ BEFORE THE MEDICAL SOCIETY OF NEW JERSEY, UPON INVESTIGATIONS MADE PREPARATORY TO A LARGER WORK ON THE PRACTICAL VALUE OF THE SPHYGMOGRAPH.

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BY EDGAR HOLDEN, M. D.,
NEWARK, N. J.

NEW YORK :
WILLIAM WOOD & CO., PUBLISHERS.
1871.

7. F. 4.

THE SPHYGMOGRAPH

AND THE

PHYSIOLOGY OF THE CIRCULATION.

It is now nearly three years since the difficulties in the way of using the Sphygmograph of Marey, and of understanding its tracings, led me to devise the instrument already laid before the profession, through the *Medical Record*. I now propose to discuss the science of Sphygmography, from a rational standpoint: omitting all possible technicalities, and so far as the subject will admit, all the abstruse speculations heretofore indulged in by the eminent gentlemen whose names have become familiar in connection with it. To this end, it will be necessary to describe briefly the instruments devised to carry on my observations, viz :

The Sphygmograph, already referred to.

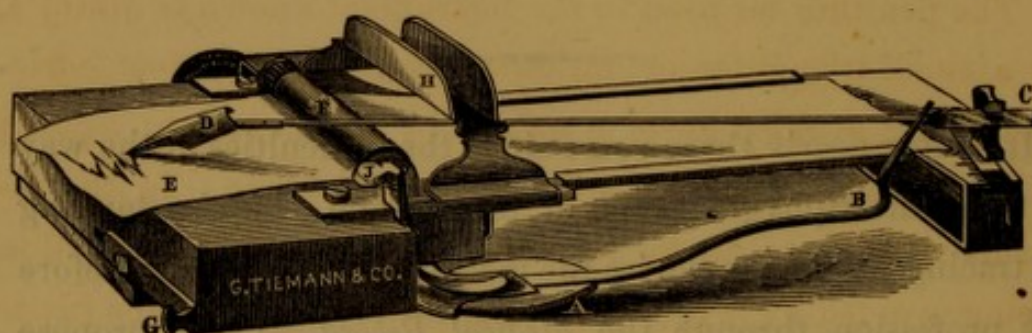
An artificial Heart and capillary apparatus made of rubber.

A large Sphygmograph two feet in length, adapted to record its workings.

In addition to these, many interesting observations have been made by attaching a long flexible lever of light wood at

one end, and passing under it, near the attachment, an ordinary india rubber one inch hose, connected with a steam engine. A lever six feet in length, produces a tracing about six inches in width, which may be varied by varying the weight, by obstructing the orifice of delivery, by interposing dilations or constrictions in the tube, &c., &c.

In regard to the first point named, the drawing will be explanatory.



- A**—A piece of ivory to rest upon the pulse.
- B**—A wire bent to impinge against C.
- C**—The tracer.
- D**—The pen.
- E**—The paper to receive the tracing.
- F**—The roller to move the paper.
- G**—Starter for watch work.
- H**—Piece by which to hold the instrument.
- I**—Spring for ascertaining the compressibility of artery.

A Sphygmograph, as is well known, is essentially and simply a light lever with pen attached to one extremity adapted at the other to receive the impulse of the artery or heart ; with this pen or tracer must be means of moving a paper at an even rate to receive the writing.

These are the essentials ; but simple as they seem, the experience of forty years has shown it to be a most difficult matter to accomplish the result desired.

Refine the parts to a marvelous degree of delicacy, obtain the movements of the lever over the artery, and move the paper or other receiver with the utmost precision, yet, apply the pen to the paper and the infinitesimal friction stops its movement ; a hair, even, will render it motionless.

The pen thus far used in the instrument known as Marey's, is a small triangular or rather conical piece of steel,—friction being avoided to some extent by its movement against a perpendicular instead of a horizontal plane. In the instrument I have introduced, any pen may be attached, friction being avoided by pivoting the pen, thus requiring the paper and not the tracer to support its weight. The other part of the instrument, and which in fact constitutes its novelty, is based upon the fact that a cone made to impinge against a flexible lever, will move it a distance proportionate to the angle made by the periphery of the cone with its axis. In this case the detached periphery is used for convenience. In short, a lever resting near its attachment upon the pulse is bent at its distal extremity into an inclined plane, which impinges against another straight and very light lever, carrying a pen.

The pen rests upon a strip of paper which is moved, as in Marey's instrument, at the rate of about three inches in ten seconds. A sliding pressure spring rests upon the piece of

ivory designed to bear upon the pulse, by which the compressibility of the artery may be ascertained.

The pen may be fed with ink, by the ordinary writing pen or pencil brush.

The time required to take a tracing with this instrument, is from one to three minutes ; and as no fastening is required, the observations made have not been marred by the fears of the patient, or the difficulties usually experienced in maintaining perfect quiet.

The artificial heart referred to, was made as near as possible of the natural capacity, and the capillary circulation designed to bear a similar correspondence between its parts, as exists in the arterial and venous systems of the human subject ; its difference from the heart in propulsive and contractile power being compensated by the avoidance of a too great extension or reduction in size of the smaller capillaries.

Farther reasons for believing this artificial heart to be a fair representation of the natural organ, will be hereinafter stated.

It is perhaps necessary to state that this heart is a single one ; that is, having but one auricle and one ventricle, since the peculiar formation of the human organ is evidently but to accommodate the double nature of the systemic and pulmonary circulation, and the partition walls between auricle and ventricle make it in nowise other than essentially single.

The wonderful structure of the semi-lunar valves, by which beautiful provision nature closes a circular opening by three

segments of hollow spheres, and which, as the perfection of mechanical contrivance challenges our admiration, has been successfully imitated only by closely following nature.

Thus in examining these valves in the heart, we observe that while the aorta is cylindrical above them, it is triangular below; and that the line of attachment of each curtain falls below the plane of its free border. The curtains, moreover, are the segments of a hollow sphere, and being drawn in at the points of attachment, really form triangular instead of spherical approximation. In imitation of these, thin rubber valves have been found to work admirably.

The auriculo ventricular valve is of more easy construction, being simply a drop valve, and in this heart was made of leather.

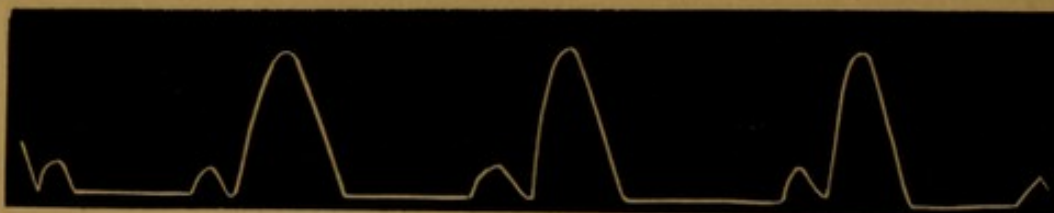
3d. The large Sphygmograph, for recording the workings of this artificial organ, is so arranged that any of the tubes may be introduced behind the tracer, near its attached extremity. The tracer is two feet in length. The slips of paper are two and one-half inches by twenty four. The pen,—an ordinary writing pen, pivoted on the tracer—the work for moving the paper,—clock work and the result—tracings in many instances, two inches wide.

With these means of observation, I have arrived at certain conclusions, in support of which, the time and space allotted for this article, are too limited to give tracings in detail. The following, however, are submitted in brief, with the free admission that some of them are very perplexing.

1.—ARTIFICIAL HEART. Large arteries, with no obstruction.



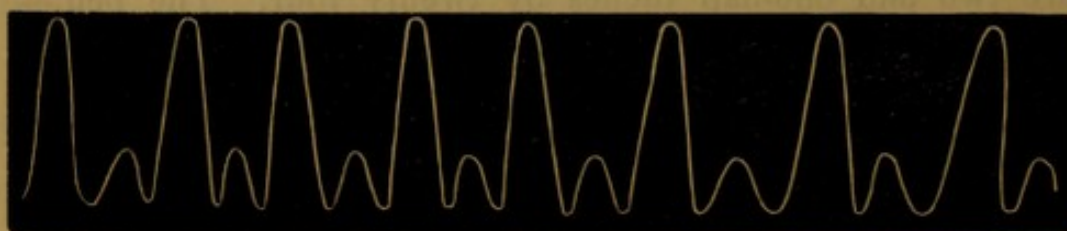
2.—PROXIMATE ARTERY ; i. e., Artery of about relative proportion to formers of axillary to subclavian. Slight regurgitation auric. vent.



3.—SAME, with considerable regurgitation. Auric. vent.



4.—NEXT SIZE VESSEL ; proportionate to Brachial. No regurgitation.



5.—VESSEL OF MEDIUM SIZE, just beyond a net of capillaries.



6.—MEDIATE ARTERY ; relative size that of femoral, with auricular regurgitation.



7.—SAME, with anæmia.



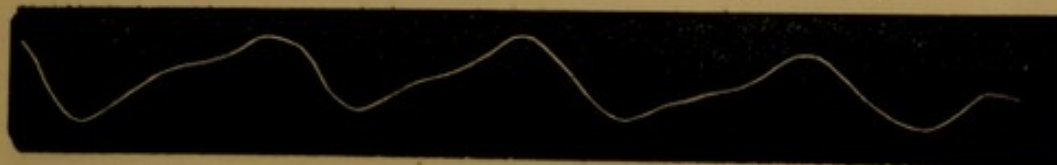
8.—A VESSEL ; relative size femoral, between two sets of capillaries ; no obstruction.



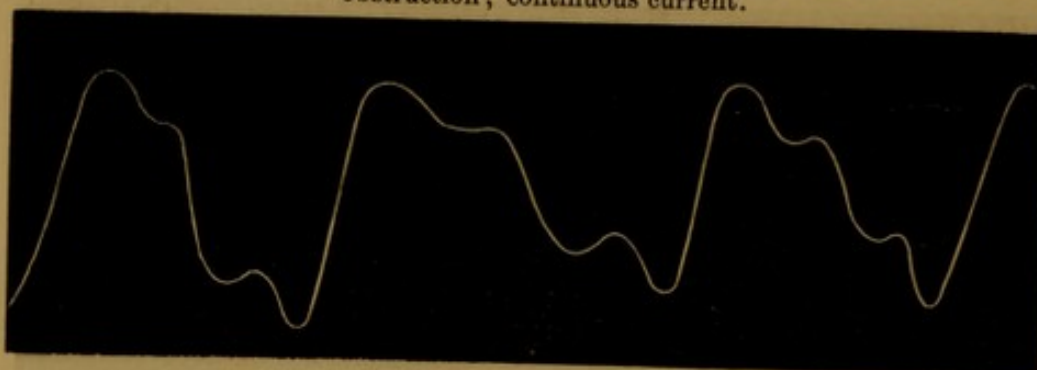
9.—IMPAIRED FORCE OF CONTRACTION.



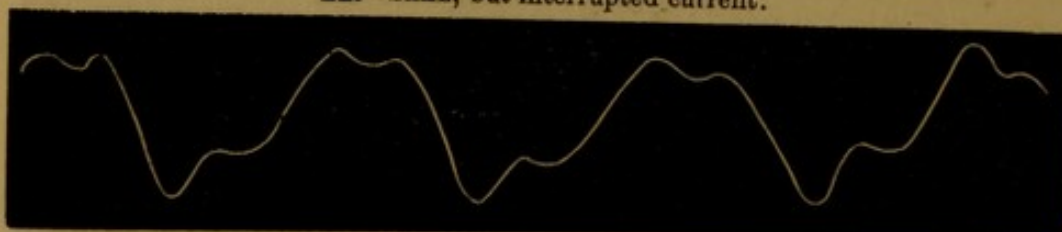
10.—NEAREST APPROACH TO RADIAL PULSE, REVERSED.



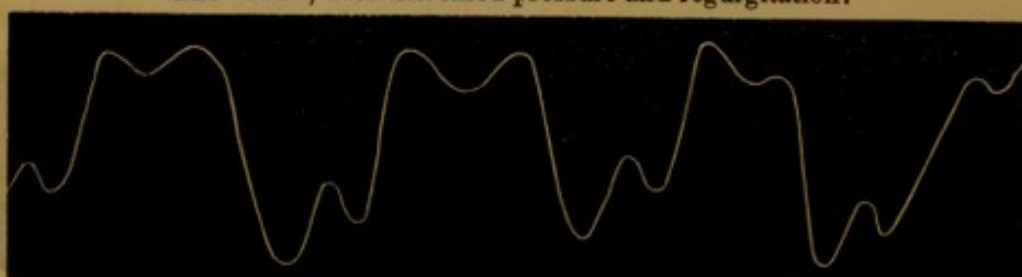
11.—HYDRANT STREAM. Great pressure; common $\frac{1}{8}$ inch tube; distal obstruction; continuous current.



11.—SAME, but interrupted current.



12.—SAME, with increased pressure and regurgitation.



Two points only will at this time be referred to regarding the experiments made with the rubber heart. The first touches the transmission of impulse; the second, the origin of the first and second sounds. The violent and sudden contraction of the heart was observed to produce acceleration at the auricle, or what is really the distal end of the circulating apparatus, in about one second, the usual interval between the healthy beats of the normal heart; consequently, when I caused a new contraction of the ventricle, the fluid from the former was

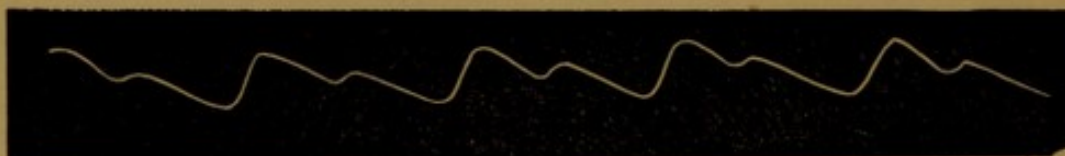
already pouring into the auricle, as is presumed to be the case in the natural organ. Now the relative calibre of the veins to arteries in this apparatus, is not, as in the human heart, as two to one, but considerably less, to accommodate the far less distance to be traversed by the fluid, so that the fact of the interval of transmission of impulse I have assumed to be evidence of sufficient approximation to nature for all experimental purposes.

The feature of chief interest, however, relates to the origin of the first and second sound—the contraction of the ventricle closed with a dull thud the auriculo ventricular valve, while the interval of contraction, during which the obstructive circulation at the capillaries backed up, so to speak, the current of fluid, closed the semi-lunar valves with a soft note, not unlike that of the human heart. We may have, therefore, a second sound, without the “accessory muscular noise of contraction;” “the stroke against the thoracic walls,” “the rush of blood through the orifices,” or the tension of the auriculo ventricular bands.

Prominent among the requisites to proper interpretation of sphygmographic hieroglyphics, is the understanding of di-crotism. Usually this departure from the smooth, regular tracing of vigorous health, of which the following is an instance :



is supposed to indicate a condition of increased venous and diminished arterial pressure, which allows retardation of the current through the capillaries, and produces an irregularity in the descending portion of each wave thus :



DICTOTISM.

Now, while under some circumstances, and with Marey's instrument, this is the case, yet in the following tracings from persons in perfect health, there seems reason to believe that refinement in the delicacy of the instrument we use may show even a tricrotic condition to be a normal one, thus :



Miss H.



Miss S.

TRICROTIC NORMAL PULSE.

Theoretically, this might be expected, if we but reflect upon the true cause of the phenomena. I have observed, in operating with the artificial capillaries, that however long the circuit might be, provided always sufficient care be exercised in maintaining the relative calibre of the smaller tubes, the

current of efflux from the large veins is never continuous. The large Sphygmograph always detected the intermission, even during the most rapid contractions of the heart, yet the tracings from any tube on the proximate side of the capillaries and the capillaries themselves, with exception of those emptying directly into the larger tubes, were invariably dicrotous. Were this owing to obstruction, our experiment would have given, as will also be found to be the case in aneurism, a continuous stream at the distal end of the circulation.

Dicrotism, then, may exist, even when the circulating medium is so rapidly dispersed in its onward course as to preclude any idea of obstructive retardation from venous pressure ; and, therefore, it follows, that the secondary wave, or slight rise in the descending line, which constitutes dicrotism, is to be regarded as not purely a wave of rebound, due to such retardation of the current.

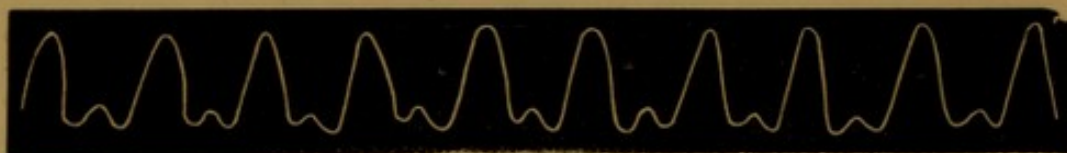
What, then, is the cause of dicrotism ? I believe it to arise simply from the fact that the capillaries are peculiarly elastic, their dilatability and elasticity being increased as their calibre diminishes. Each impulse, therefore, transmitted through them, produces (however briefly) a dilatation, an over-fullness, which re-acts upon the contained current, to produce a superficial retardation, such as is seen along the banks of a running stream.

Such a return current would inevitably repeat itself, as the circles are repeated around a pebble thrown into the same stream ; our power to number these repeated waves

depending solely upon our facilities for observation and the delicacy of our instruments.

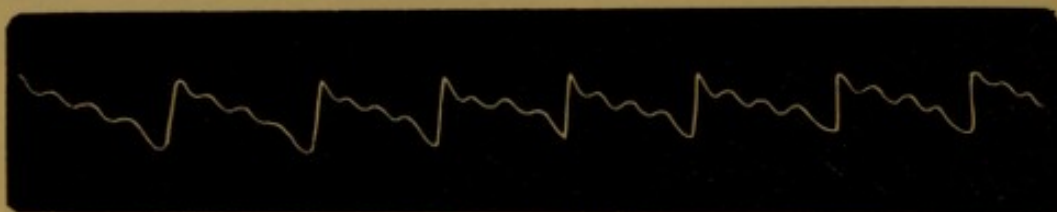
Now, if actual obstruction does exist in addition, either from inflammatory stasis or from a more common and general cause, viz.: irritation of the capillaries during fevers and the hyperæsthesia resulting from derangement of the great sympathetic system, this dirotism or tricrotism will be markedly increased.

The following is the pulse of mild pyrexia:



MILD PYREXIA.

The next are two most interesting exhibits of the effect of purely sympathetic action. They are from the abdominal aorta of a patient, (Miss W.,) who suffered for several months from a distressing pulsation, sufficient to raise the bed-clothing and to be noticeable across the bed-chamber. The radials



ABDOMINAL AORTA.



ABDOMINAL AORTA, WITH RESPIRATION.

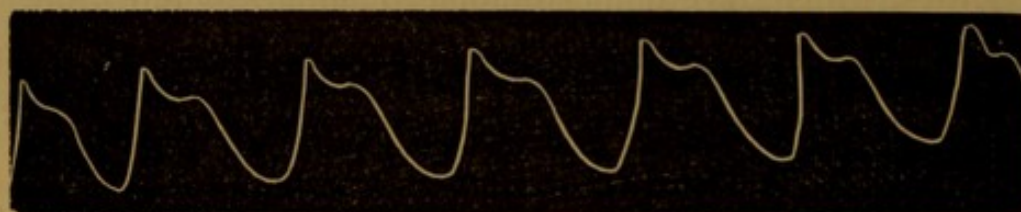
in this case gave similar tracings, but less wide and markedly tricrotic.

This case acquired considerable additional interest, from the fact that a year previous a supposed cancer had been removed from the patient's breast, by a charlatan, and there seemed reason to fear that similar disease might have attacked some abdominal organ. The diagnosis afforded by the Sphygmograph gave great relief to the anxieties of friends, which was shortly after justified by complete recovery.

Keeping now clear, as far as possible, of the abstruse technicalities, which have done so much to embarrass our knowledge of Sphygmography, let us study the pulse-tracings from a rational, common sense stand-point. Suppose, for example, we have before us the hose of the ordinary fire-engine, as constructed in its primitive days, before the alternate pumps were devised, and when, as a consequence, the stream of water thrown was perceptibly intermittent. The tube, from the instant the piston has ceased to descend and the volume of water has been forced through it, begins to collapse with a rapidity proportioned to the size of the delivery pipe. When the second stroke comes, the flattening hose swells, and the hand or a lever placed upon it is raised; now, if the impulse has been sudden and of short duration, and the delivery be unobstructed, the lever is raised vertically, and instantly descends, so that a pencil at the end would describe merely an ascending and descending line in the same plane; but if a paper to record the pencilling be moved evenly along, the

rise and fall of the lever would give a cone-shaped tracing. Should, however, the fullness be prolonged, either by the prolongation of the impulse, or by some obstruction immediately in front of the point of observation, the lever would remain raised as the paper moved along, and the wedge would be flattened at the top.

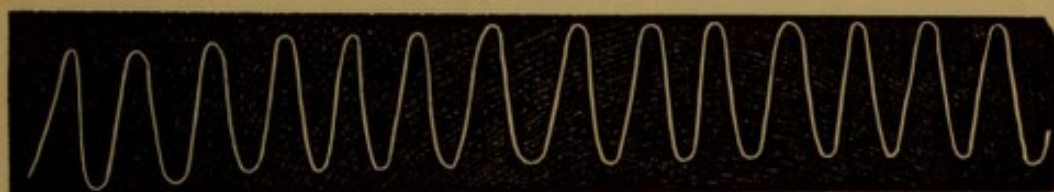
If the force exercised had been very sudden, the tube, if at all elastic, would have been a little more than filled, (*i. e.*, distended,) and the lever would fall back a trifle before entering upon the plane, thus :



Suppose, however, the obstruction be more distant and the stroke of the pump slow, a regurgitant wave would result that would have a point of commencement in the downward line proportioned to the time that should elapse after subsidence of impulse and the distance of the obstruction; thus it might even be in the valley between the curves, or even so late as the beginning of the next upward line.

Now, as will be seen in the tracings made with the large Sphygmograph already described, this is actually the case. In these instances, dicrotism does arise from obstruction, although as stated, I cannot believe it to be the usual cause in the human system. It is probably, however, the explanation of the

kind of dicrotism seen in the tracings of mild pyrexia, already given. If the propulsive power be weak, or the amount of fluid more than sufficient to completely fill the hose, no regurgitant wave would be expected ; and, as will be seen by reference to the records of the artificial heart, none results. The wiry pulse of carditis is of this character, thus :



If, instead of a tube like the leathern fire-hose, a very elastic and distensible tube of rubber be used, two points of difference arise : a tremulous character of both waves and a quicker expenditure of propulsive force ; but there being no increase of emptying power, a rounding of the summits of the curves results.

All these features, thus enumerated as belonging to the hose of a steam fire-engine, will be found in observations upon the human apparatus ; but to go farther, we must suppose the tube, instead of terminating in a single delivery-pipe, to divide and sub-divide into numerous branches, the united calibre of which slightly exceeds that of the main tubes. We have seen the results of proximate and distal obstruction, and it remains to inquire what would be the effect of interfering with the circulation through one or more of the sub-divisions. Numerous experiments have shown me that so long as the

total carrying power of the remaining branches does not very materially differ from that of the principal vessel, there is no perceptible change ; but as this diminishes, the relative tension of the larger tube increases, and the collapse succeeding each impulse becomes less ; thus, what in speaking of arteries is termed compressibility, is diminished.

With the human circulatory apparatus this tension of the arteries necessarily supposes a corresponding want of fullness of the veins, and the tracing exhibits characteristics similar to that already given for carditis.

But not to go farther in this direction, let us inquire into the changes produced in certain familiar pathological states :

1st.—Tricuspid Regurgitation.

It is well known that where this morbid condition exists, a visible pulsation of the jugulars occurs ; not always or often regular, and pulse like, but tremulous and variable, and indicating two things in regard to the blood current. 1st—An intermission of impulse or almost an absence of impetus at the venous and distal end of the circuit ; and, 2nd, a retardation of capillary venous circulation, sufficient to prevent fullness of the large veins. To ascertain what should be the character of the sphygmographic tracing in this variety of disease, let us analyze the condition that exists. 1st.—As the right ventricle forces the blood into the lungs, a regurgitation into the auricle would produce the same want of vigor of im-

pulse in the pulmonary current, as a rent in a pair of bellows would produce in its current of air. 2nd.—(As a consequence of the former) feebleness of pulmonary circulation. 3rd.—A retardation at the pulmonary valves, with imperfect impletion of left auricle and ventricle; and, finally, (supposing for the moment, the heart to be otherwise healthy) a contraction, with diminished resistance. So far the result would be a suddenness and briefness of the first stroke, similar to that usually ascribed to hypertrophy; but another factor must come in: retardation of pulmonary circulation involves imperfect oxygenation of blood; this, with regurgitation into the right auricle, produces fullness of all the venous system, and, as a result, the heart itself weakened, contracts against, not diminished, but increased resistance, and, the first part of the curve is flattened or rounded, while the second or smaller wave is more marked; in other words, dicrotism is increased, and, the curve would be this:



2nd.—Mitral Regurgitation.

Incomplete closure of the valves of the left heart presents features somewhat similar to those of the right, with a difference however, that will be manifest upon an analysis similar to that already instituted; for example, the leak into the auricle impairs the propulsive force of the ventricle, however

violently the heart may beat, or however much nature may have endeavored to remedy the impairment by muscular accretion.

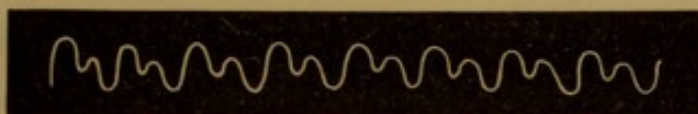
The arterial half of the system is less powerfully distended, the ingress of blood to the auricle from being persistently checked by the regurgitant flow prevents a sufficiently rapid depletion of the venous half, and as a result the first half of the tracing would be shortened and rounded at the apex and increased dirotism occurs, although to less extent than in case of the tricuspid valves. One curve taken from my record is this :



usually, however, the tracings are quite irregular.

Before proceeding farther it should be stated that in this variety of disease a great diversity exists in the sphygmographic tracings, and only large experience will enable us to decide with accuracy when it is before us. The fact that a new and simple instrument is now available, will, it is hoped, result in such numerous observations that a definite key may be found, and what is now complex become exceedingly simple. Beyond this diversity, moreover, there exists a source of error, due to a strong resemblance which the tracings often bear to those of other conditions; for example, during typhus there is an undulatory character given to the tracing, but

taking the following from Professor Sanderson's work, as a sample, it will be seen that the curves of both waves are more rounded, and the intermediate reversed curves are also rounded, so that the writing appears the same when inverted, which cannot be said of that dependent upon mitral regurgitation, thus :



A third tracing, bearing some resemblance to these, is that found in cases of great vital exhaustion, in which the heart fails to maintain the proper relation as to arterial and venous pressures. This may or may not be associated with cardiac disease; excitement, however, changes its character completely, thus :



EXHAUSTION.

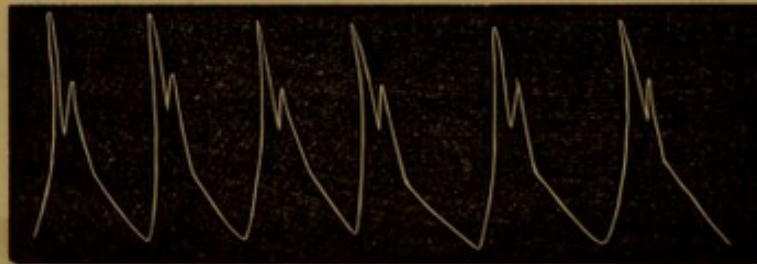


DO. WITH EXCITEMENT.

3rd.—Aortic Regurgitation.

Where insufficient closure of the aortic semilunar valves occurs, features are presented quite distinct from those described; thus, the term collapsing is peculiarly applicable to the pulse in this disease, which seems suddenly to yield under

the pressure of the finger. The stroke is quick, as if indicative of some local cardiac irritant; it is wide from increased impulse, and the apex of the first part of the tracing is sharp; the descent considerable, and the reflex wave, both because of suddenly decreased propulsion and greatly increased resistance from venous fullness, produces a sharply defined dicrotism, the line from the second prominence of the tracing itself dropping suddenly. The latter phenomenon would probably be impossible were it not for a dissemination, so to speak, of the blood back through the half emptied larger arteries; the characteristic curve is therefore as follows, (from a patient):



AORTIC REGURGITATION.

Pulmonary Regurgitation.

In this form of disease, concerning which Dr. DeCosta remarks, very little is known from clinical observation, it would be difficult to form a theory since the pulmonary circulation and the right ventricle are chiefly, perhaps solely, involved, and eccentric hypertrophy is constant.

The arteries, moreover, that are accessible for tracings are out of the track of the impaired circulation. The condition,

however, in which a murmur exists at the third left costal cartilage, near the sternum, whether with impulse or second sound and due to disease at the apex of the left lung, a condition in fact where pulmonary regurgitation is simulated, but does not really exist, gives a tracing characteristic of obstruction near the heart, and of which the following three cases are examples; the first is a case of tubercular disease of fifteen years standing, with a marked murmur.



Mrs. H.

The next the same disease, but of about five years duration, and accompanied by dilatation.



W. J.

The next a case of Phthisis florida, but accompanied by great debility, the features of which predominate in the tracing.



G. D.

This properly introduces the matter of obstructions, and inasmuch as certain features have already been referred to, it

may be mentioned that a distinctive one, between the tracings last given and those of semilunar aortic obstruction with hypertrophy, is to be found in this, that the upward stroke of the latter is more vertical, higher and ends in a sharp point, the descent being slight and then merging with a sharp curve into the plateau of the first wave, thus :

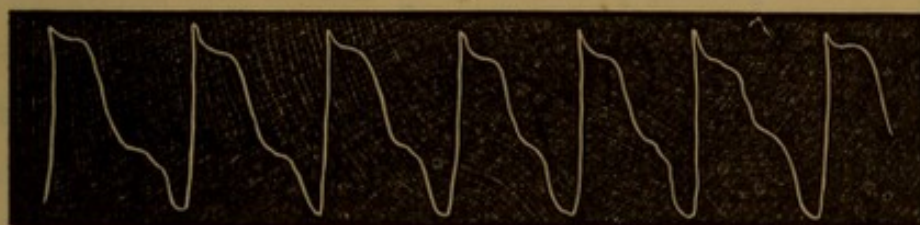


The ages of this patient and the first of the phthisical cases given were the same.

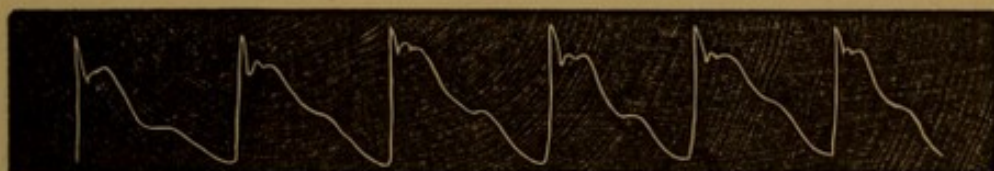
This record is however apparently identical with that of insufficiency accompanied as it usually is by hypertrophy, the variety in height, width and definiteness of outline being considerable under the modifying circumstances of excitement, debility or atheromatous degeneration of arteries.

Whether the minute shades of difference in these curves shall ever become significant, of course depends upon the number and character of multiplied investigations. One feature seems certainly to belong to them, viz: that the nearer to the ventricle the obstruction happens to be, the more definite, *ceteris paribus*, becomes the flattening of the apex of the first curve of the tracing, distant obstructions as in the capillaries of the extremities seem to exhibit themselves in the second wave of the writing or in the interspace between the first and second, or sometimes by a tremulous waviness

of line toward its end. In proximate obstruction, such as has been already described, or that produced by want of elasticity in the large arterial trunks, or by congestion and disorganizing diseases of organs liberally supplied with blood, as the spleen or kidneys, many observations and careful study of the tracings will be necessary to establish rules for interpretation. Still, even to an unskilled observer, the difference between the following records taken from Dr. Burdon Sanderson's work, will be sufficiently obvious.



HYPERTROPHY OF THE LEFT VENTRICLE, WITH DILATATION.



CHRONIC BRIGHT'S DISEASE, WITH CONTRACTED KIDNEY.



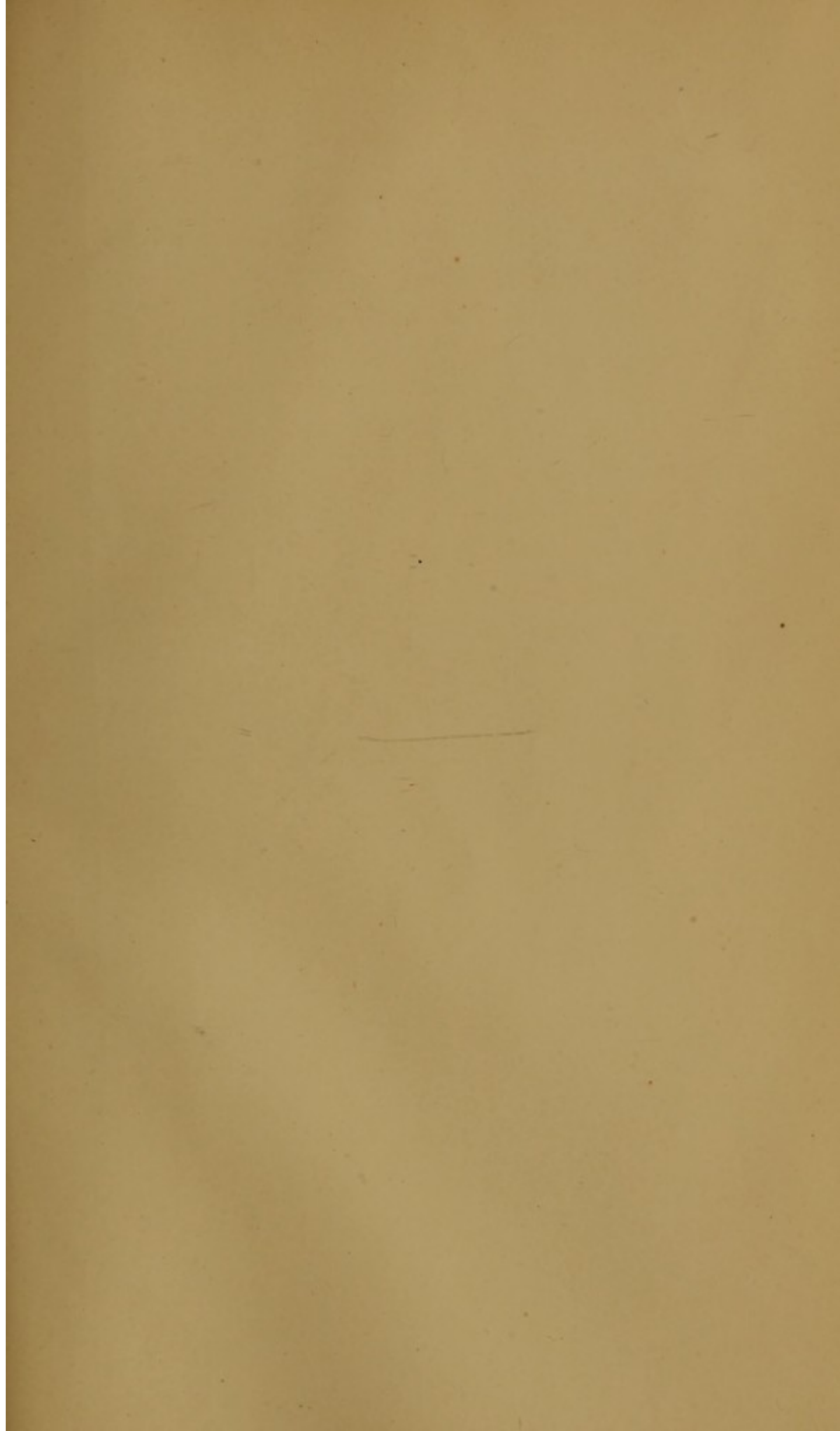
SAME DISEASE, BUT WITH LESS VIBRATILE PULSE.

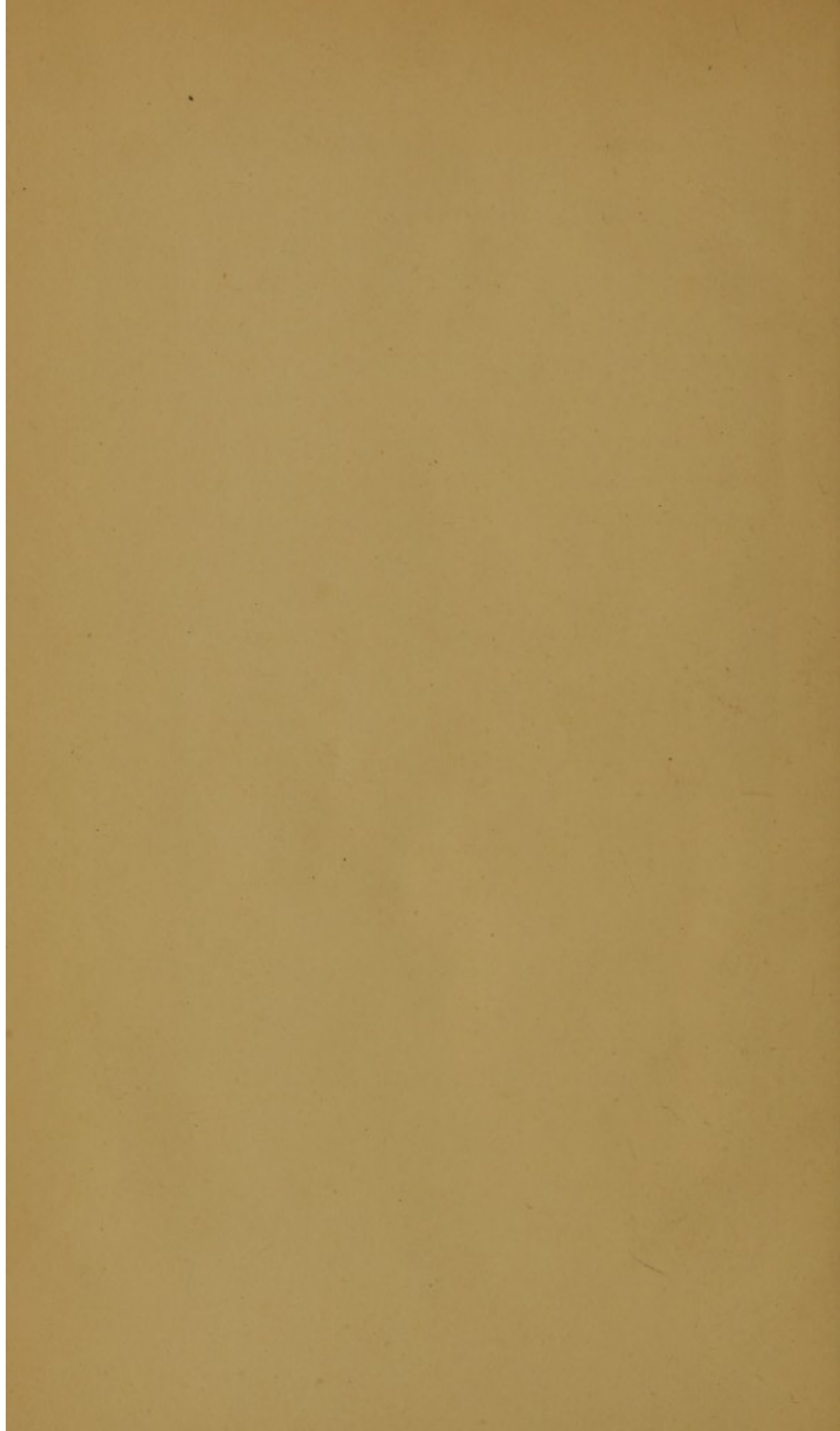
Now, so far as specific diagnosis goes, the science we are considering being in its infancy, is therefore far from perfect; thus tracings *apparently* similar result from very diverse sources,

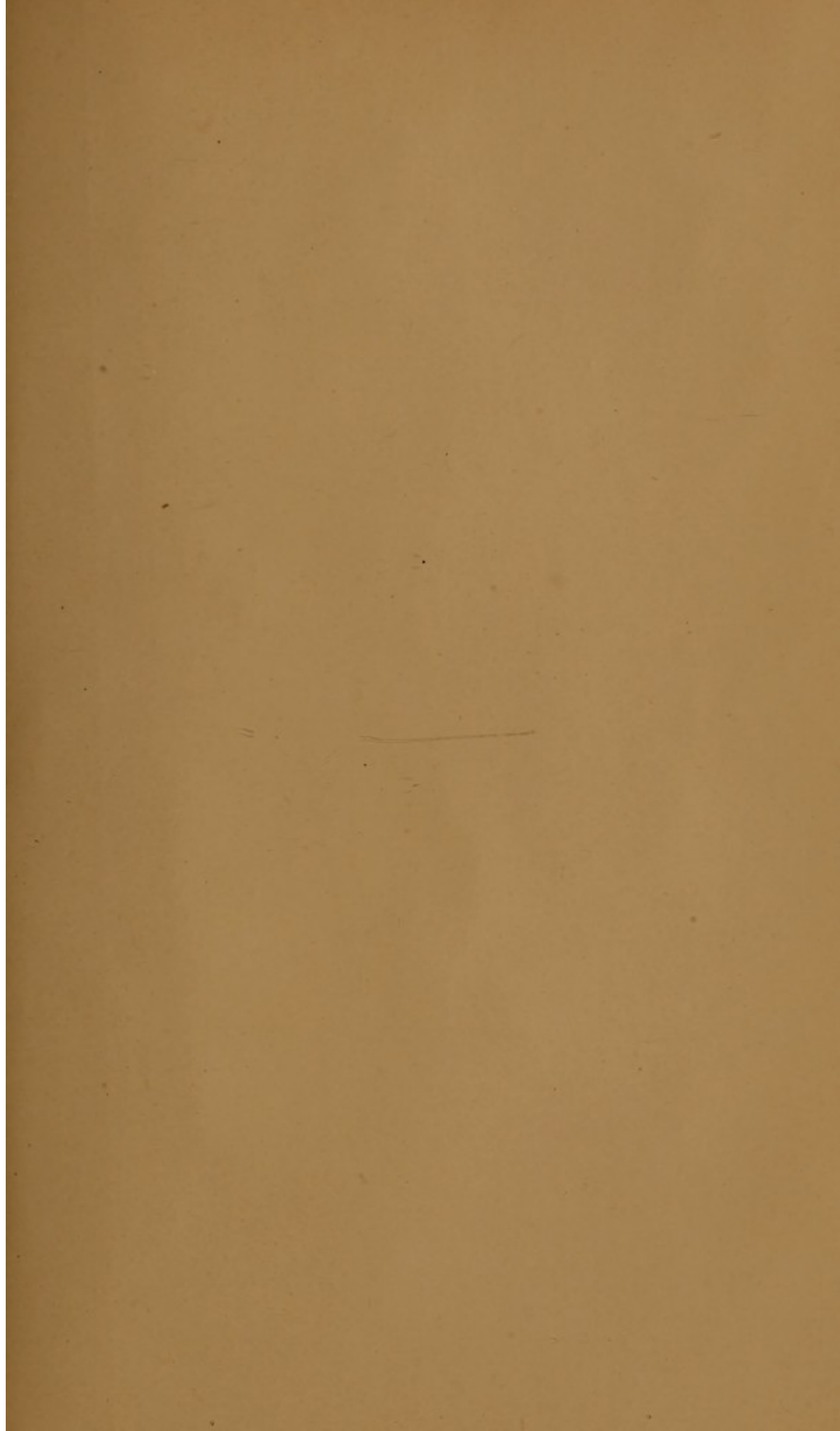
and our knowledge is at present too limited to enable us to read the hieroglyphics at first sight, always correctly ; for example, in mitral obstruction the tension of the auricle necessarily reacts upon the pulmonary circulation, and this in turn upon the right ventricle which supplies it. If the obstruction occur at the tricuspid orifice, a similar reaction exists through the *venae cavae*, the liver, the portal circulation, and thus even upon the direct aortic current. Moreover the pressure of tumors upon large arteries, even derangement of the sympathetic system, produces very similar and therefore perplexing records. Still, even though we may not say as yet just where obstruction exists in certain cases, or why, if we but ascertain *that* it does, the advantage in making a prognosis, or in estimating prospects of longevity, will be incalculable. It is here proper to say that I have thus far touched chiefly upon cardiac pathology, that this essay may not be too greatly lengthened. Morbid conditions in all parts of the body present tracings of great interest and value, and as we have at command other means of certain diagnosis in cardiac and arterial diseases, it is perhaps even outside of these that sphygmography is of greatest clinical importance. At some future time I hope to present to the profession a more extended and definite series of observations. In concluding for the present, however, permit me to express an opinion at variance with the fears of some who have found difficulties in the practical application of sphygmography, remarking that we should not allow our rules for interpretation to be too

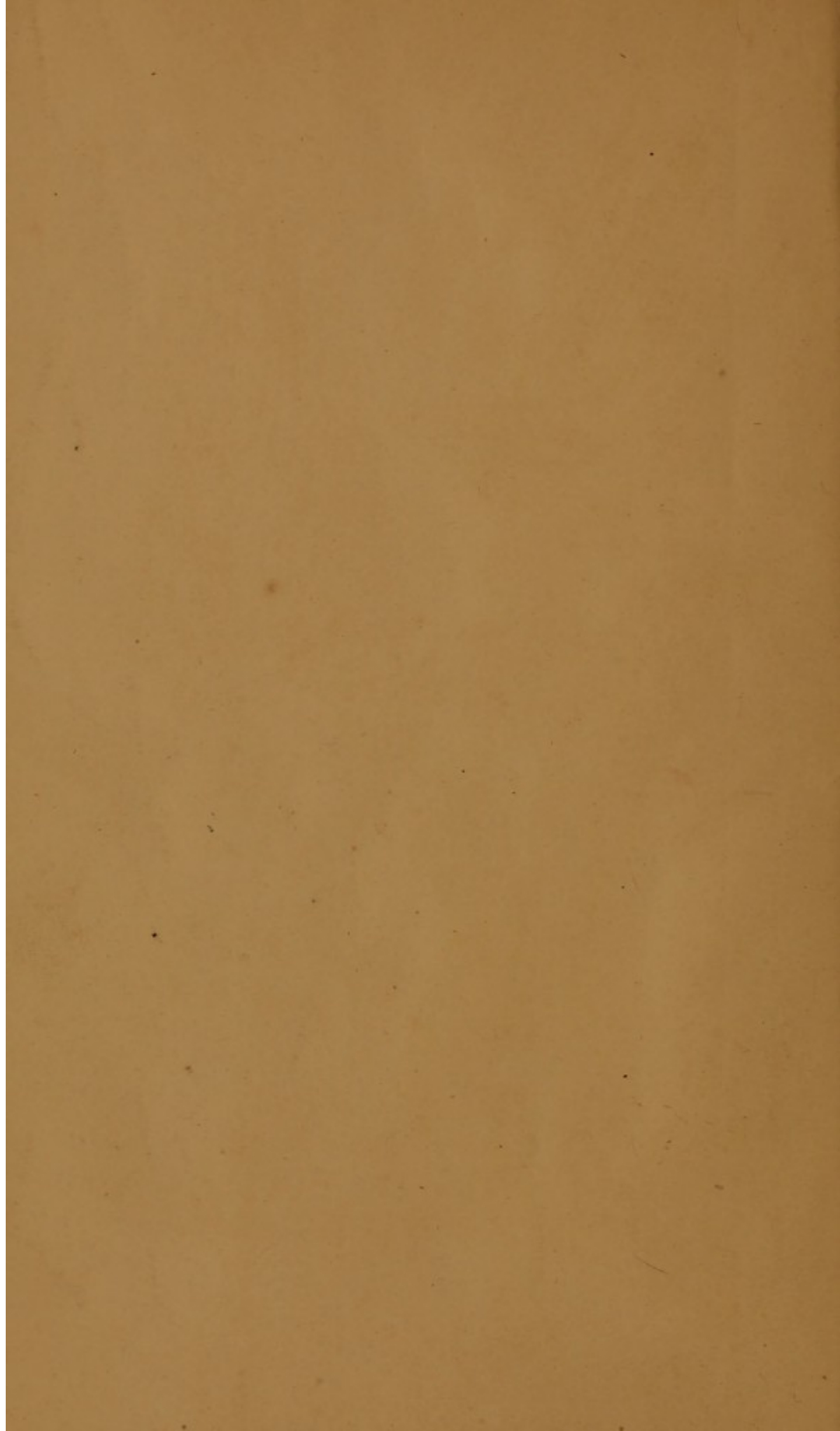
hastily formed, inasmuch as hitherto the expense and complex nature of the instrument used, the experience requisite to acquire dexterity, the difficulty of successful application and the loss of valuable time in each case, have limited the number of workers and their observations.

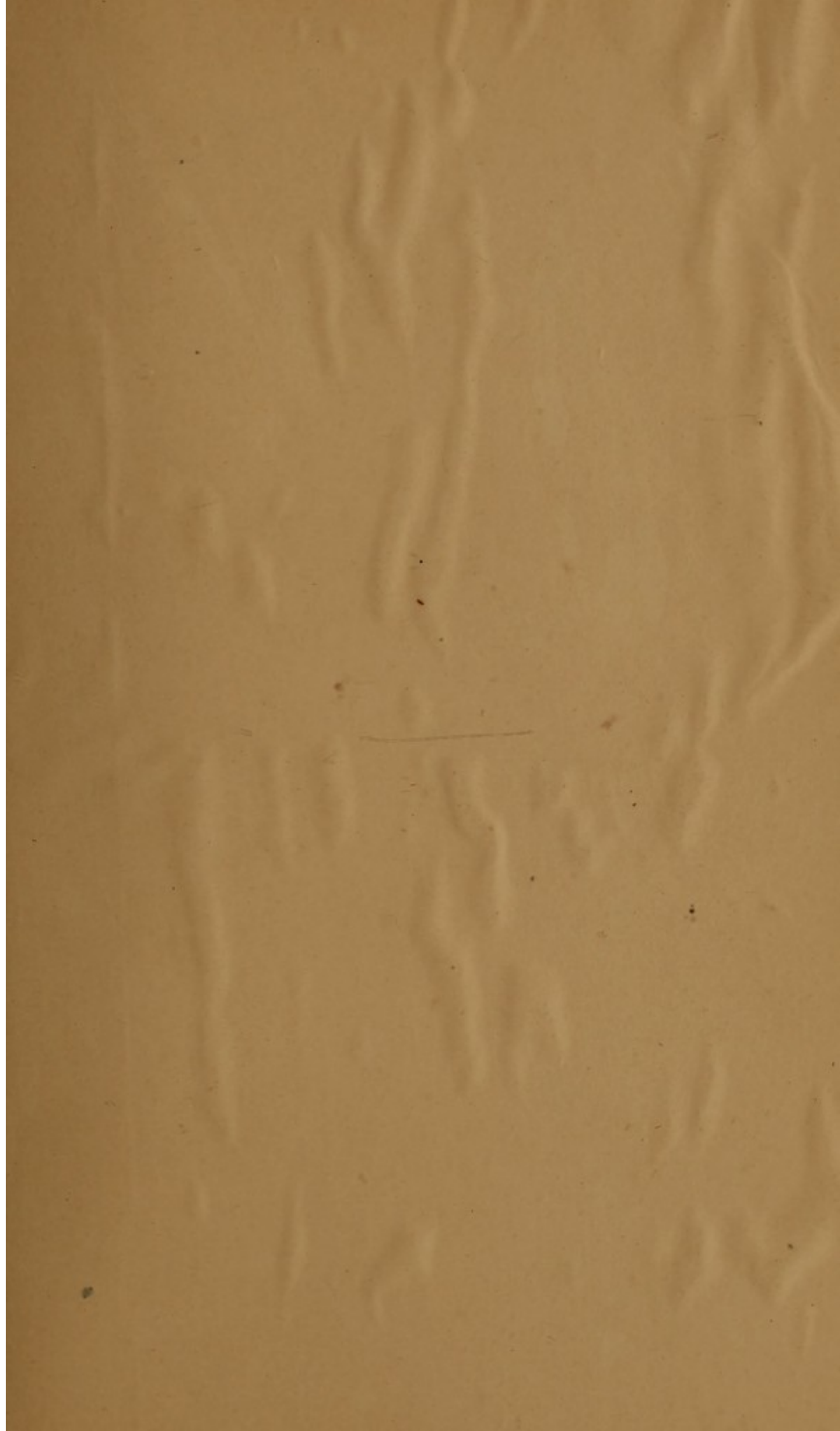
With a new principle and a simpler and less costly instrument within reach, sphygmography will rise into a definite and useful science. Certain it is that by it, even now, in its immaturity, we may detect deviations from perfect health, not discernable by any other means, and consequently in at least one, and a growing interest in this country, namely, the estimation of possible longevity, it will be invaluable.











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