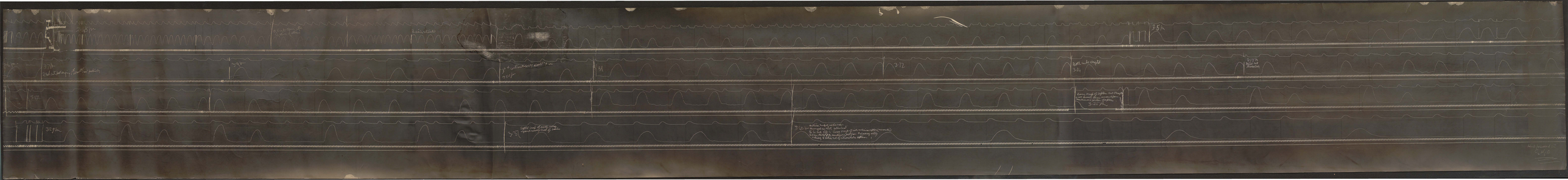
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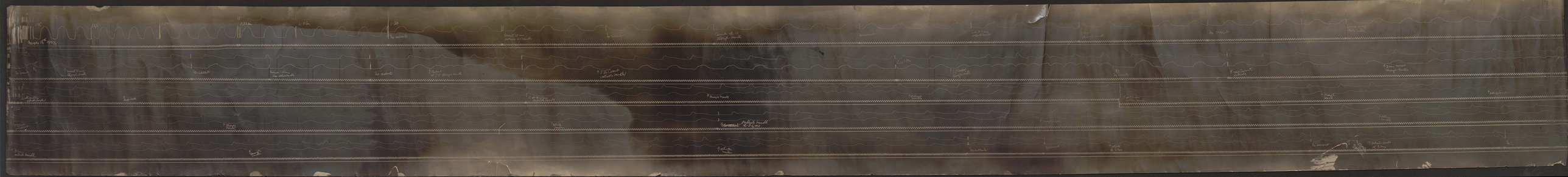
This tracing shows one experiment where the pars membranacea septi was unusually large, & dissection away of every scrap almost of muscular tissue of the septum, sufficient to produce complete heart-block. Probably the a-v bundle, either divided earlier than usual, or passed high up across the pars membranacea & so was not entirely divided across.

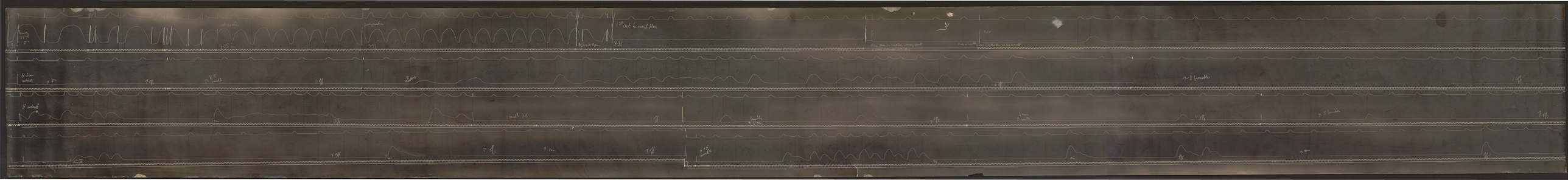
The time is marked in $\frac{1}{20}$ of a second.



This tracing shows the ~~con~~ relative sensitiveness of the incent a-v bundle and the ordinary heart muscle under Faradic stimulation.

It is noticeable that there is an absence of auricular extra systoles.

March 16th 1911



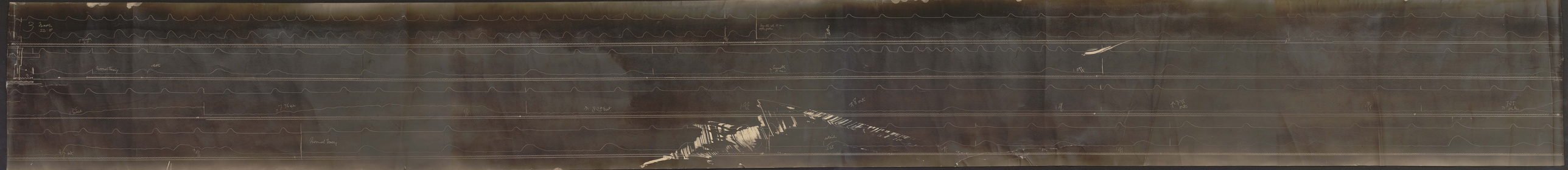
This Tracing shows the effect of stimulation of the cut a-v bundle & the normal heart muscle by Faradic current.

In this the first paper - the ventricles have not recovered their own spontaneous rhythmicity, which is seen returning in the second paper.

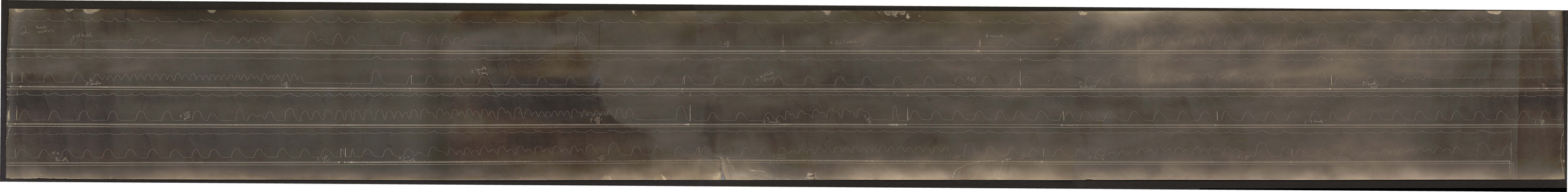
"Outside" indicates stimulation of the ventricular walls.

"Bundle" indicates stimulation of His' Bundle at the lower edge of the cut.

Mavek 27 1/1


3 hours
22.9
Normal Tracing
Normal Tracing

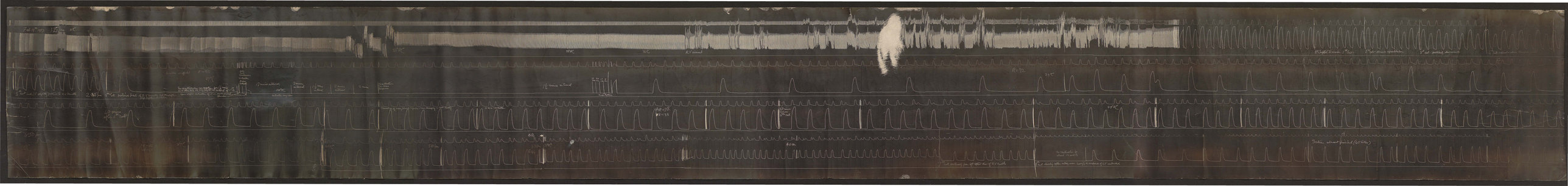
In this paper (3rd) normal
a-v conduction has returned.
The a-v bundle is therefore
further cut & quite divided.
On one occasion, stimulation
of the lower cut end of the a-v
bundle, produced only auricular
acceleration & no ventricular
response



In this paper (2nd) the ventricles begin to resume their contractions, and shows that there is still some A-V conduction.

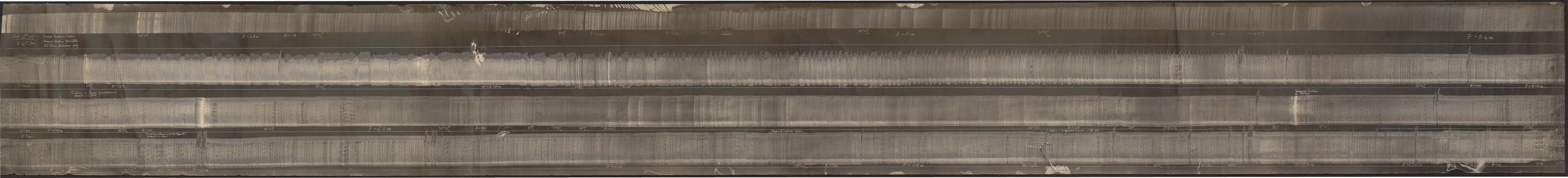
March 22nd

9



This tracing illustrates the production of auricular extrasystoles caused by the ventricular contractions, though there is complete heart-block.

This experiment is briefly described on pages 68, 69 & 70. (Experiment Seven)


Feb 11th 1900
2 45 pm.
Small Tectonic Shock
Felt in Sydney, New South Wales
25 Miles perpendicular
Silica or Sugar (underlayer)
Sugar (underlayer)
Normal Tectonic Shock
Vertical Tectonic

This experiment represents a fairly successful experiment.

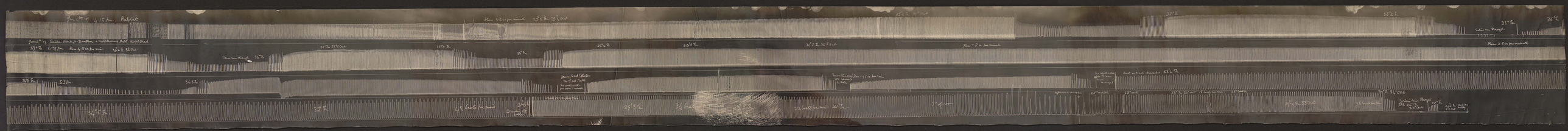
The lever gives seven-fold magnification.

The heart was small for this size of beat.

The experiment was stopped at 5.55 pm & the heart cooled and appropriated & left hanging from the apparatus all night.

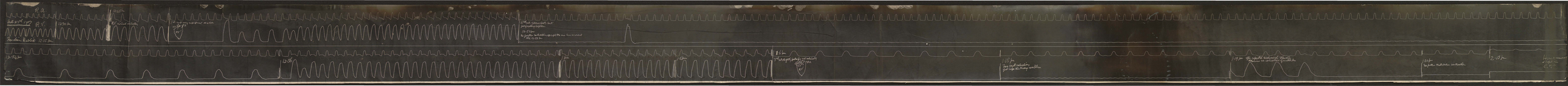
Next morning perfusion was restarted & the heart commenced beating fairly well, but the flow did not rise above 1·7 cc per minute, & 2% dialysed Tenco produced a typical Potassium effect, from which the heart did not recover, even under fresh saline, massage & high pressure of fluid, sufficiently to be worth recording.

Had the heart been kept in saline during the night, the result might have been better, as its outlook had cleared somewhat

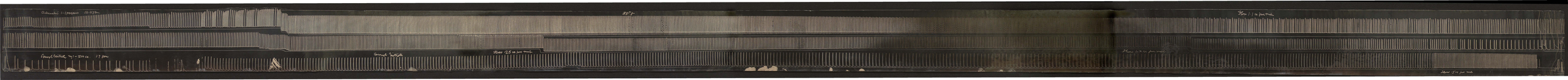


This tracing shows an uncommon form of irregularity, due probably to the excessive temperature - over 38° C.

It also shows the effect of the heart being exposed to the cold air of the room. The type of contraction alters considerably in the lower part of the tracing.



This tracing is exceptional in the length of the ventricular stoppage after section of the a-v bundle. The positions of the septal incisions were roughly noted at the time on the diagrams on the tracing.


Orthochloric 1-1000000 12-2.7pm.
Powder Particle 74 - 50 oz 17 pm.
Amorphous Particle
Flow 2.5 oz per minute
Flow 1.1 oz per minute
Flow 0.5 oz per minute
Flow 3 oz per minute

Showing Adrenalin effect, and partial recovery under Amyl Nitrite, the flow increasing from ·25 cc per minute to 1·2 cc. but soon diminishing again to ·5 cc per minute

61217

# THE PERFUSION OF THE MAMMALIAN HEART WITH LOCKE'S FLUID, AND INVESTIGATIONS OF THE BUNDLE OF HIS.

The subject of perfusion of the heart with a saline fluid, by means of which it retained its contractility for a considerable period of time, has been studied for quite a quarter of a century, but only comparatively recently has the mammalian heart been successfully perfused by this method.

In 1875 Muranowicz,[1] experimenting on the frog's heart, found that incinerated blood-ash formed, when dissolved up with water in certain proportions, a fluid which would sustain the heart's contractility for a considerably longer period of time than would a plain salt solution. From this Gaule[2] jumped to the conclusion that it was an alkaline carbonate in the blood-ash which made the difference, and which probably was the sustaining, or at any rate, the chief sustaining substance. Following out his theory he found that the addition of an alkaline salt of sodium, in even minute quantities, to the normal saline solution, enabled a frog's ventricle to continue contracting and contractile for a considerably longer period of time than he had ever found it to do with his usual salt solution. He concluded therefore that a frog's heart can feed on its own tissues, and from them, either direct or as the products of their metabolism, obtain under suitable conditions material or materials which

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1. Arbeiten aus der Physiol: Anstalt zu Leipzig.
2. Du Bois Raymond Archiv: 1878. p. 291.

were suitable and sufficient for a considerable number of contractions, and are of the nature of a sustaining food rather than a stimulant.

Kronecker working alone, and with Van Ott,[3] and Martuis[4] (a pupil of Kronecker's) investigating this subject of perfusion of the frog's heart in 1881 and 1882 came to the conclusion that the heart did not feed on its own tissues, but that, as soon as its nutritive fluid was no longer accessible, it lost its contractility, and that only fluids containing serum albumin were capable of maintaining the heart's contractility, and that apart from serum-albumin the heart soon ceased beating and lost its irritability, so that even strong induction shocks failed to excite any response. The fluid here used was a plain 0.6% Sodium Chloride solution, and with it similar results invariably occur, the ventricle rapidly losing its contractility and excitability even to strong faradic stimuli.

Martius,[5] maintaining his previous assertions, stated in 1882 that the results obtained by Gaule were due to the alkaline solution he used containing minute quantities of caustic soda, and that this combined with the Carbon Dioxide resulting from the muscle metabolism during its contractions, thus performing an excretory function and obviating Carbon Dioxide asphyxia , which he thought might be the cause of the rapid loss of contractility previously observed with simple 0.6% Sodium Chloride solutions.

3. Du Bois Raymond Archiv: 1881. p 569. 4.Ibid. p.474.
5. Ibid: 1882.

In 1885 Ringer[6] published several papers on his results obtained with a compound fluid for heart perfusion. He firstly added a lime salt to the plain salt solution, and found that it caused the period of contractility of the heart to be considerably lengthened even compared with the best results obtained with salt solution containing an alkaline sodium salt after Gaule's method. He found further that the character of the contractions was very materially altered, the heart tending after primary stimulation to go into a state of tonic contracture. The addition of a Physiological amount of a Potassium salt, such as the Chloride, was the means of absolutely and perfectly counteracting the harmful effect of the Calcium salt on the heart as evidenced by the character of its contractions, and at the same time the resulting compound fluid enabled the heart to maintain its contractility for a considerably longer period of time than under any previous experimental conditions.

The solution he used was as follows-

To every 100c:c: of a 0.6% Sodium Chloride solution he added 1 c:c: of a 1% Sodium Bicarbonate solution, 1 c:c: of a 1% Calcium Chloride solution, and .75 to 1 c:c: of 1% Potassium Chloride solution. Later Ringer substituted saturated solution of Calcium Phosphate for the Calcium Chloride, and added Sodium Bicarbonate up to a strength of 1 in 10,000, and Potassium Chloride 1 in 20,000. With this at the

6. Journal of Physiology 1885.

end of 3½ hours, when the experiment was discontinued, the contractions were still exceedingly good. In some experiments excitability remained for as long as 28 hours when this fluid was used for perfusion. Sometimes distilled water and sometimes New River Company's tap water was used for making up the saline solution.

From these experiments Ringer drew the conclusion that the frog's ventricle can feed on itself, by which he meant that it is capable of consuming its tissues, or of converting them, or some part of them, into a combustible material from which it draws its energy for prolonged action, or else that there is a combustible material suitable for food stored up in the tissues of the heart which supports its power to contract.

Further, he inferred that the rapid arrest of contractility on plain saline solution was not so much due to the removal of the heart's pabulum, but rather that lime and potassium salts are essential in a circulating fluid that is to maintain the necessary conditions for the changes that take place during contraction. And, moreover, that material to carry on the contractions is probably stored up in the muscular tissue of the heart, and cannot be washed out by a fluid circulating in the heart cavities, and that the amount of stored up material varies with the time of year and the condition of the animal.

Kronecker[7] while maintaining that serum albumin

7. Loco: cit:

must be contained in a fluid that is to support the heart's contractility, stated that such substances as peptones, white of egg, syntonin, myosin, mucin and glycogen are incapable of sustaining contractility, but that milk in considerable quantities, boiled or unboiled, and boiled or unboiled whey, and dialysed whey, can all act as a food to the heart muscle and so extend its period of contractility. Any lessening of the quantity of serum-albumin in milk lessened its nutritive value to the heart.

Ringer confirms this assertion, that even the minutest trace of serum-albumin is of great value for sustaining the heart's power to contract, but finds that white of egg and gelatin are also, though to a lesser degree, capable of acting as a sustaining substance to the heart muscle.

He went very carefully into the various effects which Calcium Potassium and Alkali produce on the character of the contraction, and proves each one of them to be absolutely necessary for a good circulating fluid. He found, however, that with his improved compound perfusing fluid only 2 c:c: of milk in 100 c:c: of the fluid were needed to maintain good contractions, and that Kronecker failed largely through the imperfection of his saline fluid, and that for the same reason he found it necessary to use much larger quantities of blood than Ringer found to be necessary.

Howell[8] has very carefully studied the subject of perfusion of the frog's heart and terrapin's ventricle with Ringer's solutions, and obtained good

8. Amer: Journ: of Physiol: ii. p47.

results without adding any serum, thus again disproving Kronecker's statement that serum-albumin is necessary. He supports Ringer by stating that the heart derives the energy for its contractions from material contained within its own substance, and will contract till this substance is consumed, whether or not the organic constituents of the blood are present. Further, that under normal conditions, the stimulus leading to contraction is dependent on the Calcium compounds, and that for rhythmic contractions, and for relaxation, Potassium is also necessary. He finds that an adequate artificial circulating fluid is a solution of Sodium Chloride isotonic with blood, and containing the Chlorides of Calcium and Potassium in the proportion, so far as the bases are concerned, found in normal blood. The Sodium Chloride solution seems essential only in preserving the osmotic relations between the tissues and the surrounding fluid.

In another paper Howell[9] states that the spontaneous contractions of the terrapin's heart are dependent on the presence in the tissues of dissociable compounds of both calcium and sodium, and that if either of these is absent, automatic contractions are impossible. Sodium Chloride he finds tends to produce relaxation from loss of tone, while Calcium Chloride causes a shortening from increase of tone, which may pass into a permanent rigor, and that potassium chloride antagonises the calcium salt, but only markedly when sodium chloride is present in about normal quantity, and tends

9. Ibid: 1902. vi. p. 181. (Amer: Journ: of Physiology).

to slow the rhythm and lengthen the refractory phase. He suggests that the latent period before the heart commences its automatic contractions may be the time necessary for the removal of the potassium out of the heart to a point at which its inhibitory influence ceases to act, and that the state of exhaustion, that so soon follows the use of sodium chloride alone for perfusion, is mainly due to the loss of calcium from the tissues as the result of diffusion.

Greene[10] has carefully worked with the compound saline fluids on the terrapin's ventricle, and obtained results similar to those of Howell. He finds that sodium chloride alone only sustains contractions for a short time, and that the series of contractions show an increasing rate and decreasing amplitude, presenting the appearance of fatigue, which probably indicates the removal of the inorganic salts necessary for contraction, and is not an exhaustion of the contractile substance of the muscle. With regard to potassium chloride, he found that it causes relaxation, but when it arrests the contractions the heart shows tonic shortening. With calcium chloride, the relaxation is imperfect, so that the tracing leaves the base-line and the heart ceases to beat in a state of tone. The optimum ratio for the potassium, calcium and sodium salts in an isotonic solution most favourable to the development and maintenance of contractions in the ventricular strip is 0·7% of sodium chloride, 0·04% to 0·05% of calcium chloride, and 0·03% of potassium chloride. He further found that Dextrose in an isotonic solution throws the strip into strong tone, and may produce an imperfect series of

10. Amer: Journal of Physiology. ii. p. 82.

contractions.

Increasing the viscosity of a simple saline fluid by the addition of Gum Arabic, Albanese obtained considerable improvement, but Locke has since then shewn that the improvement was due to the calcium salts in the gum.

In 1881 Martin[11] experimented with the mammalian heart in situ using the animal's blood defibrinated and warmed to the normal temperature. The blood was fed into the right auricle at the normal venous pressure, whence it passed through the right ventricle to the lungs, where it was oxygenated by means of artificial respiration. The blood returned by the pulmonary veins to the left auricle, thence to the ventricle which pumped it from there up a tall tube, whence it returned to the venous reservoir. The drawback to this method was that several similar animals had to be sacrificed to obtain enough blood for one experiment.

Later Martin and Applegarth[12] used a modification of this method. They perfused defibrinated blood from the aorta through the coronary arteries to the right auricle, thence through the right ventricle to the lungs where the blood was oxygenated by artificial respiration. From the lungs the blood returned to the left auricle and then left ventricle, which pumped it directly through the coronary arteries again. He also used calves' blood for perfusion.

In 1895 Langendorff[13] in his proceedure omitted

11. Studies from the Biological Lab: of Johns Hopkins University. ii, p: 119.
12. Ibid: 1890, iv, p:275.
13. Archiv f:die gesammte Physiol: lxi, p:292.

the lungs, and thus enabled the heart to be removed from the body, but the difficulty of oxygenating the blood properly and rapidly made this method unsuitable. Of course also all effect of the extrinsic nerves is lost. He worked with dilute blood.

Then in 1897 Porter[14] isolated the cat's heart and perfused it with the animal's defibrinated blood, undiluted, and diluted with 0.8% sodium chloride solution. He also employed dogs, diluting the defibrinated blood with an equal quantity of 0.8% salt solution made up with tap water. In 1898 Porter[15] found that feeding the isolated mammalian heart through the coronary veins, or the veins of Thebesius, with blood serum alone will maintain rhythmic contractions for hours when surrounded by oxygen at high tension; and that portions of a ventricle surrounded by oxygen at a high tension will continue beating if fed at quite low pressure.

For some seven years now Locke[16] has been studying the problem of perfusing the mammalian heart with a modified Ringer's solution, and has thoroughly worked out the best proportions of the different saline ingredients in it. He emphasises the necessity for oxygenating the saline fluid, pointing out that it is of the utmost importance for the maintenance of the heart's contractility. He also draws attention to the need of carefully prepared distilled water for the saline. It is to him we owe practically all that is known about the perfusion of the mammalian heart with a saline fluid.

14. Journ: of Exp: Med: ii. p. 392. 15. Amer: Journ: of Phys: i. p. 511.
16. Centralblatt f: Physiol: 1901. xiv. p. 672.

Since then Kuliabko has successfully perfused the hearts of criminals and of newly born babies with saline fluids.

Last year Brodie and Cullis performed a large number of experiments yet unpublished, to investigate the question of the purity of the salts and of the distilled water. They found that defibrinated blood, as ordinarily collected, is deleterious, as are also most samples of serum.

In a paper published just recently Guthrie and Pike[17] working with mammalian hearts, while owning that their experiments with Locke's saline solution are "too few to warrant conclusions," state that inorganic salt solutions do not maintain the activity of excited mammalian hearts so long as albuminous fluids, Luciani's groups soon appearing, and the heart stopping presumably from exhaustion.

They further state that when the mammalian heart perfused with Ringer's, or Locke's, solution, has ceased to beat, and does not respond to strong electric stimuli, it can only be revived by perfusion with a fluid containing proteid, as White[18] stated with regard to the frog's heart.

These conclusions are in direct contradiction to the results obtained by Locke and many other workers, and are doubtless due to insufficient attention to the preparation of their saline fluid. Several of them have kept hearts beating well on saline solution for a number of hours,- a result which I also am able to con-

17. Amer. Journ. of Physiology xviii p18.
18. Journ. of Physiology 1896 xix p344.

firm from the series of experiments that form the subject of this paper. I have found, moreover, that a meat extract such as Lemco, is more powerful as a restorative though containing no proteid, than any albuminous fluid.

It is possible to maintain the contractility of a heart apart from mechanical or electrical stimuli for three days, as has already been demonstrated by Locke. And Brodie working last summer with rabbits, using Locke's solution in his own apparatus, maintained rhythmic contractions for as long as 10 hours.

Recently Martin[19] has studied at some length the effects, as far as he can ascertain them, of the different inorganic constituents of Ringer's fluid on the heart muscle of Terrapin. In a previous paper he had stated that a Calcium Salt has the function of improving the power of the tissues of the heart to make use of oxygen, especially when that substance is present in meagre amount; and that deficiency of Oxygen in Ringer's solution may largely be made up for by increasing the amount of Calcium Chloride therein contained. The activity of the Calcium ions seems to him to depend upon their presence in the tissues in a diffusible form, while normally they are found in animal tissues in an indiffusible form of some kind, and he suggests that perhaps oxidation processes may be controlled by both nervous and chemical influences affecting the conversion of the Calcium ions from the indiffusible to the diffusible form. He suggests

19. Amer: Journ: of Physiology 1906 xvi. p197.

further that they may exert their influence by making the tissue enzymes more active.

He finds that if an isolated ventricle, during the latent period before any contractions have developed spontaneously, be immersed in Calcium Chloride solution saturated with Carbon Dioxide, contractions commence at once, but that rapid cessation, as one would naturally expect, follows unless air is bubbled through the solution. Comparing the effect of a similar solution of Sodium Chloride with this one of Calcium Chloride, he finds that with the latter the contractions are stronger, but not so regular as is the case with the former. The effect of the Carbon Dioxide as a stimulus to spontaneous contraction is remarkable and interesting in view of the fact that its general effect is depressant and to cause relaxation of muscular tissue.

In discussing the Sodium Salt he says that quantity is necessary as the ions seem always and only to exert as it were a "mass influence." They do not seem in themselves to arouse spontaneous or automatic contractions, but may be absolutely essential to life, and may act by replacing by their "mass" other ions, and that the Sodium tissue compounds thus formed are favourable to the carrying on of the vital processes which are initiated by the deposed ions or other agencies.

With regard to the Potassium ions, these are normally present in the tissues in an indiffusible form, and when present in a diffusible form are highly inhibitory in their action. As Guenther[20] has shown a

20. Amer: Journ: of Physiology 1905 xiv p96.

a strength of a Potassium Salt, insufficient to check normal impulses traversing the heart muscle, will prevent any automatic ventricular contraction from arising: further that a strength that stops response to a physiological stimulus will not stop response to a mechanical stimulus. Several times as great a concentration of a Potassium salt are needed to inhibit auricular systoles as are needed to check ventricular systoles.

Apparently Potassium ions while being powerfully inhibitory are not strictly toxic, for their inhibitory action only continues so long as diffusible ions are present in the tissues: for if they are washed out with a normal solution, no harm is found to have been done. They are directly antagonistic to Calcium ions in their action, as manifested in their effects on the heart's contractions. Martin thinks that not only do the Potassium ions directly antagonise the Calcium ions, but that they further inhibit the contraction processes themselves. It is well known that if Ringer's solution containing a slight excess of Calcium Chloride, or Phosphate, is perfused through a heart, or applied to a strip of ventricle, such as terrapin's, contractility is easily set up, and the heart has a great tendency to go gradually into permanent systole, also that the addition of slight excess of Potassium salt stops this absolutely. He suggests that perhaps the Potassium ions exert their influence by forming inactive compounds with the zymogens of the tissues and also with the contractile substances of the muscle.

Working with Limulus heart Carlson[21] finds the effect of the sodium salts on the muscle, as apart from

21. Amer: Journ: of Physiology 1906 xvi p364.

the cardiac ganglion, is at first somewhat to increase the strength of the contractions, but later depression in amplitude of beat follows. Potassium salts produce depression with cessation of beat within one minute. Calcium salts seem to have no primary stimulating action either upon contractility or excitability, but produce a diminution in amplitude. The results differ from those seen in experiments on mammalian hearts, where there is at first an increase in amplitude, diminution following later if the dose has been too large. Similarly while dextrose exerts a beneficial effect on the contractility of the mammalian heart, Carlson, in the limulus heart, finds it causes diminution in amplitude of beat without primary augumentation, though on the cardiac ganglion it acts at first as a stimulus. It is, of course, to be expected that limulus heart would show many differences in its reactions as compared to mammalian heart.

The whole of the series of experiments that form the subject of this paper were with two exceptions carried out on the rabbit's heart. On these two occasions the cat's heart was used but failed to give me such good results as the rabbit's, perhaps partly through contracture of the left ventricle. For Yandall Henderson[22] has pointed out that the reason why frequently the left ventricle of the cat or dog, perfused with Locke's fluid, fails to beat while the remainder continues vigourously, is due to a contracture

22. Amer: Journ: of Physiology 1906 xvi p364.

from absence of any distending force in the left ventricle, and that, if the left ventricle be distended with fluid at a few centimetres pressure through the auricle, the ventricles begin to beat again. He has repeatedly seen cat's hearts in one minute so far recover as to be pumping a normal volume against the normal pressure of 150 centimetres of Locke's fluid: and within two minutes of the fluid being cut off the left ventricle again becomes systolic. A further reason for the employment of the rabbit heart is its much greater economy of saline, using as a rule less than half that required for the cat's heart: and this is a matter of importance seeing that the distillation of the water used must be very slow, a point which will be entered into fully later on.

My own experiments have been conducted with two main objects in view. In the first place to study the general conditions underlying the maintainence of rhythmic contractability in the excised heart, and in the second place to investigate the auriculo-ventricular bundle, commonly known as the "bundle of His".

The apparatus used throughout was that designed by Professor Brodie, and kindly lent me by Professor Schäfer. It was shown at a meeting of the Physiological Society in January 1906. Its essential parts are a central tube with a cannula at the lower end to which the heart is attached, and down which the perfusing fluid is fed: surrounding this is a water-jacket that can be kept constant at any desired temperature. All parts in contact with the saline fluid are made of best Jena glass as this gives up nothing

to the perfusing fluid. The reservoir for the saline was a Marriotte bottle so that the pressure of fluid was maintained constant.

Before commencing the experiments all the glass parts of the apparatus that would come in contact with the saline fluid were carefully cleansed, first with strong hydrochloric acid, then with caustic potash, after which they were carefully washed in tap water. It is best after this carefully to wash out the tap water with a liberal quantity of good distilled water before using the apparatus. All rubber tubing and corks were boiled in 10% caustic potash for quite half an hour to extract all antimony in them, taking care that the caustic potash reached every part of the inside of the tubing and was circulated through the tubing several times in the course of the boiling. The tubing was then carefully washed and attached to a tap so that ordinary water from the main could be run through it for the best part of an hour, thoroughly to remove all the potash, and impurities extracted by it. The tubing also should be afterwards washed through with good distilled water before use. To my mind it is of great importance to be very careful as to the cleanliness of every part that shall come into contact with the saline fluid before it reaches the heart, or with the salts during weighing or mixing. The salts were, except on one or two occasions, Kahlbaum's, as they are supposed to be the purest, and absolute purity is of the greatest importance. All measures and funnels used in preparing the saline and all flasks also were carefully cleansed with acid and alkali, tap-water, and lastly

distilled water. Filter-papers should also be pure and clean, and the experimentor's fingers should of course be clean when handling anything that must come in contact with the perfusing fluid.

In the earlier experiments glass-wool was inserted into the glass portion of the feeding-tube above the cannula in order to filter the fluid. But after the first few weeks I abandoned the glass-wool, and instead carefully filtered the fluid, after I had prepared it, into the reservoir, and then oxygenated it; by this means all that was wanted was obtained much more simply and effectively.

The real source of difficulty in the achievement of good results appears to lie with the distilled water, which must be most carefully prepared. The best part of three months constant work was taken up in solving this one point alone, and even now carelessness in the distilling will ruin an experiment. At first before one realised what was the source of trouble, every kind of expedient was resorted to, with varying results, but none enabling the heart to give good contractions for any length of time.

The still as first used, was a copper can, tinned inside, that could be automatically fed with water, and heated by an ordinary gas-ring. The steam was led by a glass tube, with a baffle at the end inside the still, to a condenser, and the water collected in a flask of Jena glass. The rubber cork that was in the top of the can was soon discarded for an ordinary cork, as the heat caused it to strongly impregnate the water with the smell of hot rubber. The next plan was to replace the

metal can by a flask of Jena glass, and a baffle was inserted in the vertical part of the tube fitting into the cork of the flask, so that a considerable quantity of distilled water was caught and fell back into the still, the quantity varying with the rate of distillation, slower distillation allowing more water to be caught by the baffle. This caused considerable improvement, but still the results were uncertain and unsatisfactory. It was noticed that when moisture freely condensed on the sides of the baffle, the water was always better, as evidenced by the behaviour of the heart. This led to the adoption of different measures to cool the baffle, so as to cause increased condensation. Only slight improvement followed. The next thing done was to employ a long glass tube to lead the steam down to a Y piece, to the bottom of which was attached a rubber tube of good size and about 8inches in length, the end of which was raised to a level about 2 inches above the upper arms. To the other upper limb of the Y was attached the glass baffle tube which led through a condenser to a collecting flask. The Y tube rapidly filled with distilled water which, before it could escape from the raised end of the rubber tubing, was of sufficient amount to thoroughly wash the water vapour in its passage down one upper limb of the Y and up through the other to the baffle, and so to the condenser. Two baffles were then inserted in the vertical limb attached to the further arm of the Y, and the free end of the rubber tube was raised to a height sufficient to cause the washing water to be bubbled well into the lower baffle. In this way the water

that came from the condenser was about half the amount that came over from the rubber tube. This alteration of method led to some improvement, and one heart went on with very vigorous undiminished beats for three hours and ten minutes, when the experiment had to be discontinued for the night.

An apparatus was then made providing for the washing of the steam as with the Y tube above described but all of glass and with the Y welded on to the baffle tube, leaving one of the arms of the Y free. Into this fitted a plain tube, inclined downward, leading from the still. This method gives fairly constant results, provided every care is taken in the distillation and in the technique of the experiment, and provided that the rabbit is in good condition.

Each time the still is restarted the first lot of water that comes over - say for the first quarter of an hour - should be discarded and collected in a different flask. On no account should more than 3 litres of good water per 24 hours be distilled over, and the water from the Y tube should be about double the quantity of that collected for experimental purposes.

Another precautionary measure I always adopted was to wash the oxygen well before it entered the saline by bubbling it through water. A wash bottle was attached to the air-inlet tube of the saline reservoir in order to make sure of the removal of impurities; and to this again a gas-bag filled with oxygen may be attached if desired, though this is unnecessary, as it is easy by shaking to so oxygenate the saline that it contains 2.3% to 3.04% of oxygen. About 1% of oxygen

was always found in the saline after use. A good shaking up with air is not sufficient though the heart will beat for a considerable time, as shaking up with oxygen will always cause great improvement in the beat.

Before each experiment every part of the apparatus through which the saline flows should be cleaned out carefully: the glass parts first with cotton wool, then tap water, and lastly distilled water. The rubber tubes should be rolled between the fingers, so that the insides of the walls are well rubbed together, after which they are washed out with water. Of course when experiments are successful such careful cleaning is not necessary, but when anything toxic has been perfused through the heart it should always be done. Such scrupulous cleanliness may not be so important as I have here stated, but by it one is enabled to eliminate another variant, so that by using the same salts every time, the only varying factor to be dealt with, as far as the saline is concerned, is the distilled water.

The preparation of the heart was as follows:- The saline fluid being made up and oxygenated by shaking several times with oxygen, the reservoir containing it is raised to the desired elevation, and connected by a rubber tube to the upper end of the central tube of the apparatus, a spring clip preventing all flow of the fluid till needed. The water jacket of the apparatus is kept at the desired temperature, generally 34 C. to 36.5 C under ordinary circumstances, and a small quantity of saline, say 50 to 100c:c: is

heated in an evaporating dish to about 36C, and placed close at hand for the purpose of washing the heart on its removal from the body. The rabbit is pithed, care being taken to destroy the medulla, as otherwise respiratory efforts may continue, and air be drawn into the heart cavity. The animal is then bled, and the thorax opened down each side commencing from the diaphragm, and the whole of the front of the chest is removed after the pericardium has been gently freed from its anterior attachment. The pericardium is next opened and removed, as it is found experimentally that the heart gets on better without it in experiments such as these, and the heart being very gently seized in the left hand is freed from below upwards with sharp scissors, care being taken that the aorta is cut beyond the middle of the transverse part of the arch. The heart is now immediately transferred to the warmed saline, and very lightly given a number of momentary squeezes to expel the major part of the blood from its cavities. The arch of the aorta is seized with dissecting forceps, and the ascending portion cut through close to the innominate arteries, in order to leave as great a length of the aorta as possible. The tissues attached above and behind the auricles are divided close to the latter, and the pulmonary artery cut across just after it has passed in front of the first part of the aorta. The heart is again washed in the warm saline, and the cannula inserted into the aorta and tied in with a ligature. The spring clip is then taken off the saline feed tube, and the bent pin with string and recording lever is attached, and the lever adjusted to

the smoked paper, and the tracing started. The lever used was of aluminium, 15cms. long and giving six-fold magnification. It appears to make no difference whatever to the efficiency of the heart for experimental purposes if even a great part of the auricles are cut off, and it is better to cut into the auricle, (the right one being the one usually damaged) than to leave much tissue attached to it. The saline now is flowing through the coronary arteries from the aorta and back to the right auricle through the coronary veins and sinus, thence through the right ventricle to the pulmonary artery, whence it is pumped on to the auricles helping to keep the outside of the heart moist. Of course, vertically below the heart a large funnel leading to a receptacle must be attached, in order to drain away the fluid as it flows from the heart.

It is best to use rabbits not quite full grown, with a heart weighing about 5grms. Small rabbits with hearts weighing 2.5grms, and downwards, were seldom in fit condition to give a long period of good contractility, and were too sensitive to any change in saline or temperature: while the hearts of very large rabbits did not settle down well to their altered conditions and surroundings. It was impractible to keep the rabbits long enough to see that all were fed alike and in good condition, but it is my opinion that this is a point well worth attention, as there is no doubt that a good experiment more often results when the rabbits are in good condition and have good coats.

Idiocyncrasy is frequently shown in the hearts experi-

mented on, some starting off well and vigorously, and others doing just the reverse for no obvious reason. It is important to avoid any sudden change of temperature by having the washing saline, and that feeding the heart, at correct and steady temperatures.

The saline used was after Locke's formula, as follows:- Per litre it contains-

9 grms. of Sodium Chloride crystals

0.42 grms. of Potassium Chloride

0.24 grms. of Calcium Chloride

5c:c: of 4% solution of Sodium Bicarbonate.

After the first few experiments the 1grm per litre of dextrose which Locke used to add, was invariably omitted as my sample seemed in every case but one to do harm, perhaps on account of its impurity, though it was Kahlbaum's.

Usually 3 litres were made up at a time, as being a convenient amount for a single experiment and for oxygenation.

Usually the flow through the heart will be only about 3 to 5c:c: per minute at the beginning of an experiment, gradually increasing to as much as 9 to 13, or more, c:c: per minute, and then falling again to an average of about 7c:c: to a minute, and remaining there for some time, and then gradually diminishing. In other cases, and these often the best experiments, the flow will start high, say 10 to 13c:c: per minute, then drop to 7 or 8, and after that settle down at 8 to 9c:c: per minute, slowly diminishing to 7, where fair constancy will be maintained till the heart begins to fail with a slow and steady decrease. The average

flow for a heart beating powerfully and relaxing well was about 7c:c: per minute. Variations occurred from 13c:c: to 5c:c:, but a flow above the former was rarely met with, and then only for a short time, unless the pressure was excessive. Even the very small hearts did not exhibit good contractility with a smaller flow than 4c:c: per minute, though they might continue rythmically for one or two hours with a flow as low as 3.5c:c:. Decrease of flow is an early sign that decrease of beat is following and indicates almost invariably, when occurring fairly early in an experiment, that the water is bad - too quickly distilled, or some want of cleanliness.

With a rapid flow through the heart the water jacket needs a higher temperature to bring the saline to the right temperature quickly enough on its passage through the inner tube: while with a slow flow a lower temperature is sufficient to warm the saline enough. For an average rate of flow a jacket temperature of 34C would produce a temperature of 32C as the saline entered the aorta. Of course the rate of flow depends to a great extent on the fluid pressure, the range of which should not be above 60cms nor below 30cms. I varied the pressure chiefly according to the size and strength of the heart and to a less degree according to the rate of flow. All that is desired is to have the rate rapid enough to supply the tissues with a sufficient amount of oxygen. A greater elevation than 60cms, while giving a greater flow, seemed to decrease the amplitude of beat and bring about no good effect, while wasting valuable saline and probably too

injuring the delicate capillaries. For it must be always bornein mind that, though under normal circumstances the pressure in the walls of the vessels is much greater than this, the viscosity of the saline is much less than that of the blood, and even at the pressures used seems to damage the epithelium of the capillaries and cause some oedema of the tissues. Thus a lower pressure is undoubtedly the best to work with, and in my opinion should average 35 to 40cms.

The best temperature at which to keep the saline as it enters the aorta varies from 30C to 33C. With a heart that starts off with a rapid beat and good flow 30 to 31C is ample, and serves to slow the heart very materially and prevent its rapid fatigue: while with a slow beating heart 33C would be quite suitable, and often 34C would be needed before the heart would quicken its beat and relax well between each contraction. In my experience it is unwise to exceed 34•5C as diminution of beat almost invariably follows. In the first experiments I constantly tried to keep the heart at a temperature somewhat approximating that which it is accustomed in the animal's body, but found as a rule rapid fatigue set in, while the contractions were so rapid as to have small amplitude and never any pause between the beats. 35•5 to 37C was the range of temperature at first and occasionally 38C would be reached, not purposely, but through want of practise in regulating the temperature of the water bath. Then the improvement following the accidental fall of several degrees would show that a lower temperature was desirable. At 38C a true 2 to 1 rythm would usually develop with

a fairly rapid decrease in amplitude of beat and cessation unless the temperature of the saline were lowered. Often this occurred at 37C, and when the heart was giving poor results the temperature of 36.2 has produced the same result. Delirium cordis never seemed to occur, though in one or two cases the heart developed a very hurried action, each succeeding contraction being larger than the last, for some 10 to 15 contractions, and then stopped and resumed in a second or two at a very slow rate with small amplitude: In about 15 seconds the rapid series started again, and this alternation continued till cessation suddenly came or the fluid was cooled.

As a rule the heart will contract more powerfully if exposed to the air of the room, the difference of temperature between the inside and outside acting as a stimulus. The cooling of course producing a slower rate of beat with slow relaxation and calls for a somewhat higher temperature of the saline, say 35C. The drying of the outside of the heart was not great and did not under ordinary circumstances produce any evil effects.

At first I used to heat up the saline in the reservoir but found that this method cracked the bottles, decreased the oxygen content and did not give one such control over the temperature as when one starts with the saline cold and warms it as it passes through the water-jacket.

Two or three experiments were carried out with the heart in situ. The cannula was inserted into the right innominate artery, the left innominate and

the first part of the descending aorta being ligatured. A second cannula was inserted into the pulmonary artery, the venae cavae being ligatured. The animal was then bodily immersed in a bath of salt solution at about 35 to 36 C: and kept under the surface by a weight. The saline was as usual fed into the aorta at about 40 to 50 cms. pressure and led from the pulmonary artery into a receptacle at a few centimetres pressure. In another experiment no cannula was inserted into the pulmonary artery, but the fluid was fed through the right auricle into the right ventricle, thence through the lungs to the left side of the heart, whence it was pumped up a tube about 40 cms. in height into a vessel where it was reoxygenated and used over again. However the greater difficulty in the technique of this method far outweighs the slight advantage gained, so that the simpler method with the isolated heart was invariably adopted. It was found out by these experiments, however, that the right ventricle was as a rule unable to pump against a pressure of more than 5 or 6cms. of fluid, both it and the right auricle gradually becoming more and more distended till contraction failed. The left ventricle on the other hand pumped up to a height of 40cms. without much trouble.

The bent pin attached to the recording lever was usually stuck into the right ventricle about 3 mm: from the apical part of the inter-ventricular sulcus, for it was found that the force of the beats given by the left ventricle often begins to fall off early in the experiment, while the right ventricle continued giving

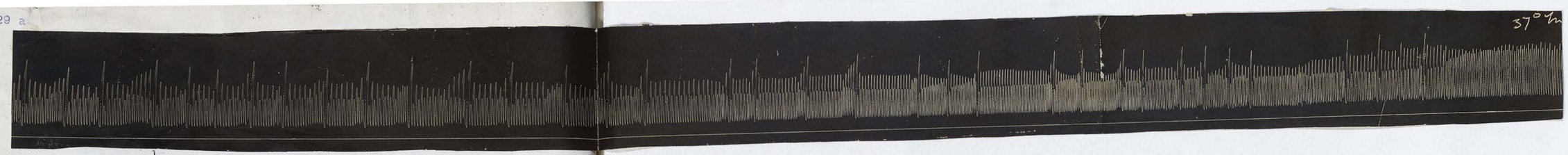
beats 5 or 6 times the size for a considerable time.

When the heart is contracting well and relaxing fully between the beats, it will be found usually to adopt a rotatory motion, travelling during each systole spirally for about a third of a circle in the direction of the hands of a watch, and as it were unwinding during diastole.

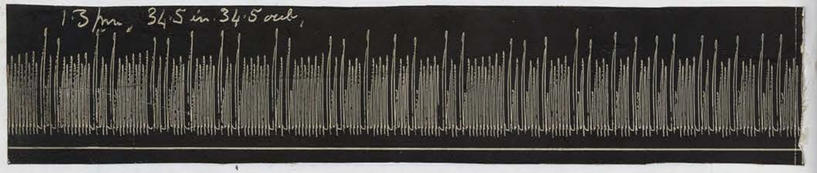
It was frequently found, quite early in the experiment, that emptying the left ventricle by clipping the feed tube and releasing a small side tube leading out of the cannula close to the heart, for two or three seconds only, will often cause considerable improvement, the heart rapidly steadying down to the work before it. It acts beneficially by allowing the left ventricle to empty itself, which it seems on occasions unable to do against the pressure of the fluid in the aorta.

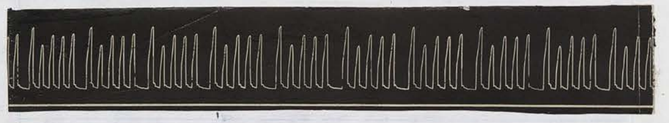
All the records were taken on smoked papers 7 feet long, and on the average one round took about 45 minutes, but the rate of drive was varied considerably.

Most of the early experiments show arhythmia, and too high a temperature was almost certainly the cause. For apart from a high temperature, an alternans type of beat is practically the only irregularity found in these experiments, after the heart has settled down to its work. When arhythmia is developing, the groups of contractions are long, perhaps 9 or 10 beats occurring between the pauses, but they rapidly shorten to 5 or 6 beats in each, or even less, and if irregularity is increasing to a fatal termination, the groups grow smaller, 4, then 3, then 2 beats between the pauses, till a half ventricular rate occurs, which seems to be a

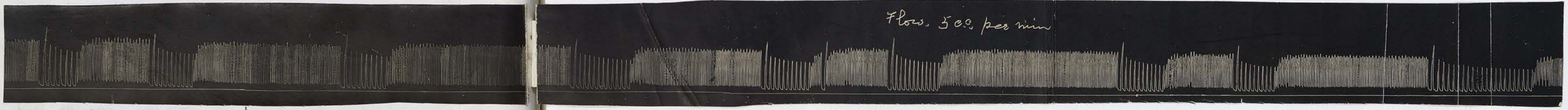



"Pseudo-groups," leading to recovery. (see p. 30)

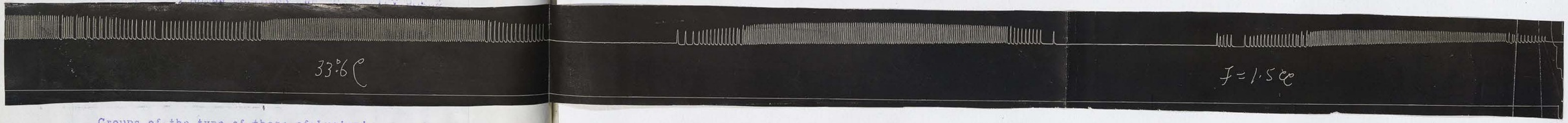


True groups produced by some toxic body in the saline.
(see p.28)




Arhythmia that often followed the use of Dextrose.




Groups of the type of those of Luciani.

true 2 to 1 rhythm, after which the contractions diminish rapidly, with other irregularities, till the heart stops. At any stage of its course the declension may gradually revert through longer and longer groups to the normal rhythm or an alternans of close approximation in height of beat. The return towards the normal is always slower than the decline, gradually lengthening groups appearing with increase in size of beat.

The pause between the groups appears to be of the nature of a missed ventricular contraction, as though the heat had impaired the conduction of the auricular impulse, or greatly diminished the contractility of the ventricles. It is midway in length between the sum of two pauses and one systole, and the sum of one systole and one pause, that is about 1¼ of a normal cycle. There is another variety of grouped arhythmia occurring before the heart has steadied down, which is somewhat similar, but the pause is simply caused by fatigue after a series of tumultuous contractions, and the pauses are relative to the contractions and of varying lengths.

As a rule, after the pause comes the largest contraction of the series followed by the smallest. If the group is one of four beats, the 3rd generally exceeds the 4th contraction, although they are often equal and of normal size; while if the group is of five the 3rd and 4th are often about the same - the 3rd often a little the greater - and the 5th larger. If the group is only of three the 1st is greatest, the 2nd smallest and the 3rd is intermediate and about the normal beat. If the group is of six the 1st is greatest, the 3rd is next, the 4th is again smaller, the 2nd least of all,

While the 5th and 6th beats are normal. Measurements such as these occur (in millimetres):-

Group of 4- 22,8,16,14, 20,12,14,10. Average = 14.

Group of 3- 20,8,15.

Group of 5- 14,9·5,12,12,12·5.

An alternans beat may vary from less than half to only a slight difference in the size of the two beats.

In the case of the pseudo-groups we get much the same arrangement as to size of beats, e.g. 24,8,11,10, 10·5,11,12,11,12, but the heart rate is much more rapid, and usually more vigorous, and it is a condition that usually improves, whereas when real groups occur they tend to end fatally unless the cause be removed.

One interesting type of irregularity that occurred as the result primarily of a temperature of 38.5C inside and 39C outside, is one in which suddenly a half ventricular rate sets in with decreasing beats and decreasing rate till ⅓ rate may be reached, when recovery will suddenly occur if the temperature has been reduced. Otherwise a pause of 1, 3 or 4 minutes occurred between the groups after which the beats were normal again. This was repeated many times till finally the heart ceased in diastole.

In some measure the effect of heat depends upon the amount of oxygen in the fluid, as reoxygenation often caused removal of an arhythmia which had developed at a temperature which was maintained without harm after reoxygenation. This may be one cause of the variation in temperature which hearts can stand, some working well at a higher temperature than others because the saline contains more oxygen. Thus in one

case a temperature of 36.2C caused the appearance of groups with diminishing size of beat, but after reoxygenation of the fluid a temperature of 37.4C did not cause the appearance of any groups. It was observed in another case in which the lever was weighted with a load of two grammes isotonically applied, the removal of the weight caused the disappearance of groups which had been present for some time. From this it seems as though the cause of these groups is a failure to obtain sufficient oxygen for the ventricles to respond to every auricular impulse under the conditions, in the first case because of excessive temperature, and in the second because of the load.

As before stated, a rise of temperature above 34C, and certainly above 34.5 is apt to cause a fall in the amplitude of the beat, while a temperature as low as 28 also seems often to cause a fall in the size of beat. But in the latter case allowance has to be made for the lessened fling of the lever, since relaxation takes place more slowly and thus a tracing shows a smaller amplitude, all "kick" having disappeared, though the heart may be contracting as vigorously as ever.

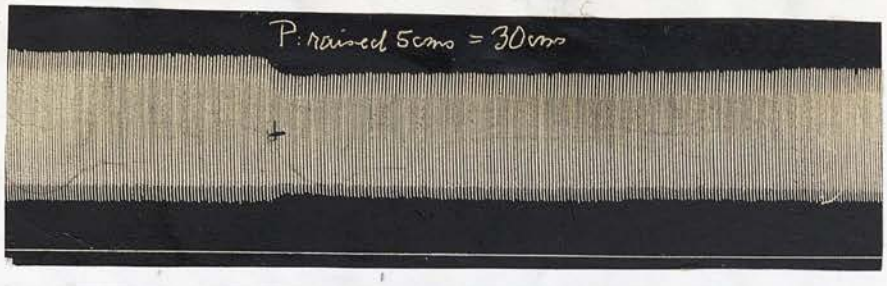
In my experience variation of temperature seems to have practically no influence on the rate of flow except at the two extremes. With a high temperature the flow is somewhat increased from the greater relaxation of the tissues, while with a low temperature the tone of the muscle fibres produces a compression of the vessels with lessened flow. But there is little evidence that the vessels themselves are capable of responding to variations in temperature in the excised

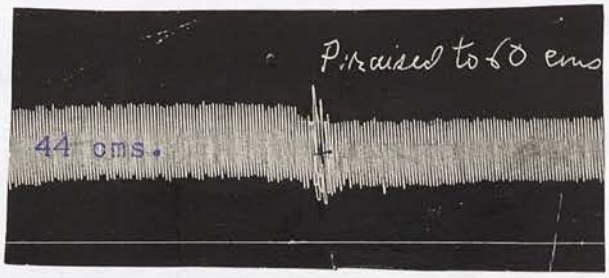
heart.

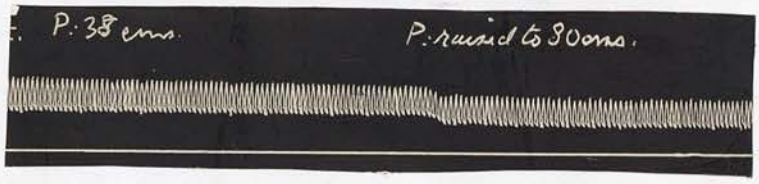
With regard to the rate of flow, there is no doubt that the main factor in obtaining an d maintaining a good flow through the coronary vessels is the purity of the distilled water, or at any rate that the flow is primarily governed by the reaction of the heart to the saline. For if the fluid suits the heart, there is a good flow and it is maintained according to the degree of suitability, whereas anything unsuitable in the saline will cause a poor flow and poor experiment. As the distilled water was the only varying factor in the experiments, one naturally, and I think correctly, lays the blame on it, though of course the toxic substance is present in it in far too minute quantities to be isolated or identified by any tests at present known.

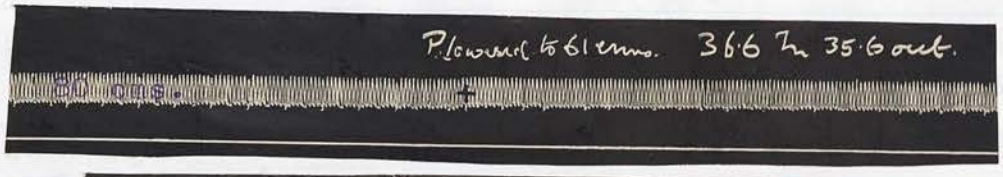
The rate of flow is largely alterable by varying the height of the reservoir, that is the pressure of the fluid as it reaches the heart. Thus it is possible to raise the flow from 4c:c: per minute to over 20c:c: per minute, as I have done, by pressure alone, and I have obtained fair contractions from a heart for quite two hours longer than one's experience led one to suppose it could possibly, under the circumstances, continue contracting, by simply maintaining a considerable pressure of oxygen in the saline reservoir, and thus perfusing the heart under a forced feed.

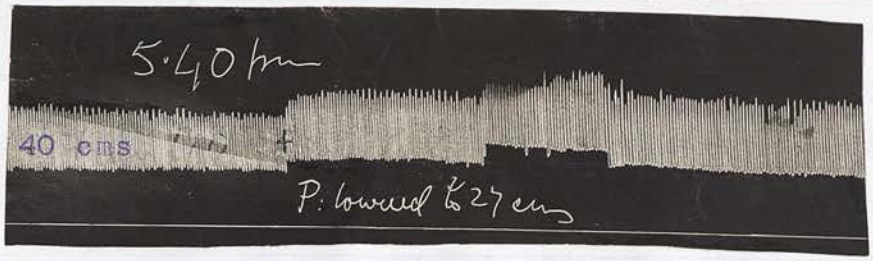
One should aim at keeping the pressure just sufficient to cause a rate of flow slightly in excess of what one would normally expect to get from that size of heart. It is best to start with the reservoir at a






Variations in the pressure of the saline.

fair height rather than to start with it too low. Thus one finds that it is best to perfuse a heart weighing between 3 to5 grammes at a pressure of 40cms; larger hearts at a pressure up to 60cms, and only the hearts of 2grms and less at so low a pressure as 25cms. If from a start of 25cms the pressure is raised to 30cms an increase in amplitude of beat will nearly always follow, while a rise again to 40cms may cause a diminution unless the heart is a fairly large one, while a pressure of 60cms will certainly cause a marked decrease in height of beat. I have not yet found a rabbit's heart that will work successfully at a pressure as high as 80cms, nor one that does well below 30cms. If during an experiment the pressure be slightly increased an improvement may follow, but any great increase seems always to cause harm.

Although at first sight it seems as though a rise of pressure causes a slowing in the rate of beat, it is found upon careful measurement that, apart from the fall in temperature occasioned by the more rapid flow through the heart, ~~that~~ variations in pressure have practically no effect on the rate of beat. In the case of a very small rabbit where perfusion had been started at too low a pressure, a rise of 3cms produced an acceleration of 24 beats per minute without any increase of amplitude, and only 0·9c:c: per minute increase of flow, showing that the original pressure was too low to feed the heart adequately. The temperature here had fallen slightly, so that the change cannot be ascribed to a rise of temperature.

A rise in pressure affects the amplitude of beat

variously. If the initial pressure be low, a slight rise in pressure will produce an increase in the size of beat, but any rise beyond this will cause a diminution again, while a return to a lower pressure almost invariably causes a still further fall in height of beat instead of improvement as one might expect.

In the early experiments I used to load the hearts with a weight varying from 1.25grms to 3grms, but never found more than a very temporary improvement, and that only when the pin was in the left ventricle, the right ventricle seeming unable to bear the extra work. So that in the majority of these experiments the heart was not weighted except for the lever.

At the commencement of an experiment the heart's rate is usually very rapid, soon slowing down and then gradually accelerating again to the rate about which it continues during the experiment. As the experiment proceeds however, there is always a very slow but steady fall in rate of beat. Roughly a variation of 1 degree of temperature produces variation of from 8 to10 beats per minute, 2 degrees about 20 beats, but a very small variation of temperature does not cause the same proportion of variation. The rate of beat has almost always begun to fall steadily before the contractions attain their maximum for the experiment, and before the maximum rate of flow is reached. The rate of flow also has almost invariably begun to diminish before the contractions reached their maximum, and all through the experiment the rate of flow indicates in advance any alteration in amplitude of beat.

The results obtained in these experiments from the use of drugs etc. will now be briefly noted.

Excess of Calcium Chloride causes a primary slight increase in size of beat and in rate while the flow is practically unaltered, but this is rapidly followed by a distinct slowing in the rate of beat with some decrease in amplitude, leading to a gradual decline in rate of flow and a shortening in the duration of the experiment. The tracing gradually rises from the base line, the heart gradually going into tonic contracture. Each individual contraction shows a rounded top with a rather slow and imperfect relaxation, the upstroke being rapid at first but slower in the last quarter.

Excess of Potassium Chloride causes the height of beat to fall without affecting the rate of beat or flow to any great extent, until the heart is beginning to stop, when both rates fall off considerably. With this drug the tracing remains close to the base line, the tissues being relaxed, while the upstroke of the contraction is sudden and followed immediately by a sudden relaxation.

The sample of Kahlbaum's Dextrose I was using, as before stated, seemed almost invariably to do harm, the heart's contractions tending to fall off more rapidly with a distinct inclination to become systolic in its type of failure. It always produced a slowing of the rate of beat. It seems in some way to counteract the bad effect of toxic substances, for when dextrose is present in the saline a larger dose of such a substance is needed to poison the heart.

Hydrogen Peroxide was tried in varying strengths, but, when strong enough to produce any effect at all,

it liberated bubbles of oxygen in the coronary vessels, and the heart soon died from distension with gas.

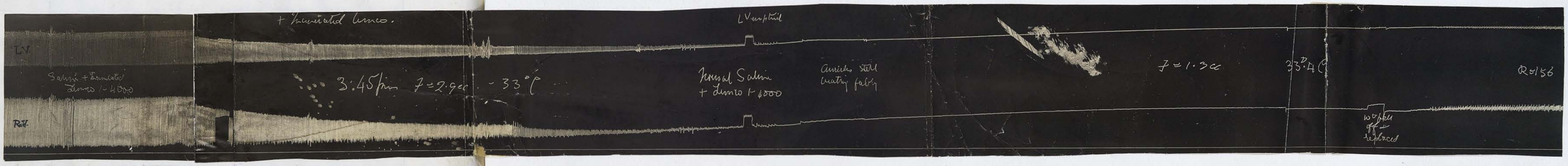
It was possible to vary the amount of sodium bicarbonate within fairly wide limits without producing any noticeable effect, from 2·5 c:c: of the 4% solution up to 7·5 c:c: per litre being tried in different experiments, though the best results were obtained with 4 to 5 c:c: per litre. The carbonate was always added to the saline before oxygenation. When the bicarbonate was accidentally omitted, the heart remained relaxed and did not contract, while the flow was extremely high.

Glycerin seemed to be very toxic, causing the heart rapidly to become systolic with marked fall in rate of beat and of flow.

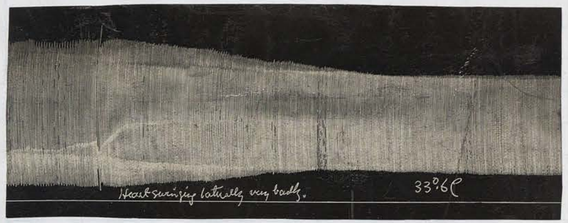
Sodium oleate was tried in strengths of 1 in 500,000 and 1 in 250,000, and caused marked fall in the rate of flow and of beat, the size of the beats declining more slowly as though primarily from the decrease of flow, and only to a lesser degree from any direct toxic effect on the heart tissue proper.

Adrenalin Chloride was used on various occasions. It was usually found to cause, in dilutions of 1 in 1,000,000, a fairly rapid and steady primary increase in both the rate and size of the beats, till they were about doubled. After this the rate and height of beat soon began to diminish, the former to as slow a rate as half or even a quarter of what it was before, and the latter back to the normal. All this time the flow seemed to be, if anything, slightly decreasing. The stronger solutions, however, did not appear to produce the primary beneficial effect, the flow and size of

Formic Acid. Usual type of effect. The flow was about 6 c:c: per minute before the drug's action commenced.




The effect of the ash of "Lemco". Probably a potassium reaction. Showing recovery on perfusion with normal saline.




The effect on the tracing produced by a marked lateral swing of the rapidly beating heart.

beat rapidly diminishing and groups occurring with a H, 3 or 4 to 1 rate of beat. The right ventricle is more rapidly brought to a standstill than the left ventricle.

Amyl Nitrite (1 minim in 500 c:c:) to a certain extent counteracts the weaker doses of adrenalin, the flow increasing somewhat again, as also the rate and amplitude of beat, but the effect is little more than that caused by a return to normal fluid, and is temporary, as decline and cessation of beat soon follow. Externally it seems to have no effect. On most occasions when it was tried its effect was nil, unless in large enough doses to be immediately toxic.

Formic Acid I tried on many occasions, as quite recently it has been used with considerable success in cases of heart disease, especially those of muscular weakness, and in chorea and in diphtheria to guard against paralysis and cardiac failure. It seems at first to cause a slight increase of beat, but a rapid decline soon follows. In the strength of 1 minim in 500 c:c: of saline there was a primary short and slight beneficial effect in a case where dextrose was present, but stronger solutions caused an immediate bad effect. When no dextrose was present, 1 minim in 1000c:c: caused a rapid decline, and in one case 1minim in 1,000,000 was tried and similarly at once produced a bad effect. The flow was increased when strong doses were used, and this may have been due to its acidity though the addition of an alkali such as sodium bicarbonate does not lessen its toxicity.

Lecethin was tried twice, pounded up with saline

in a mortar and then carefully filtered. In both cases it caused diminution of beat with some slowing in the rate of beat followed by considerable fall in the rate of flow.

Proteid of muscle, obtained by macerating the extensor muscles of the thigh in saline and filtering, was tried. When unheated it produced a tolerably rapid fall in size of beat, rate of flow and of beat, which increased till groups and irregularities appeared. The solution heated to over 70 C for nearly ½an hour and then filtered, caused marked improvement in flow and in height of beat, with a distinct slowing in rate as a rule, though occasionally this last was hardly noticeable. On one occasion, however, when heated proteid was added late in an experiment, it caused a markedly bad effect, the cause of which I could not ascertain, unless it was that the heat had been insufficient to destroy the toxic body or bodies.

I then tried Liebig's extract of meat, "Lemco," and found, in the first instance in which it was tried, that a strength of 1 in 1000, after a short primary decrease in flow, caused a great increase in the size of beat and a considerable increase in the rate of flow, the rate of beat being somewhat slowed as a consequence. The heart showed much greater stability and endurance than before. It was soon evident that this was too strong a dose, as a return to normal saline caused at first an improvement, due doubtless to an advantageous dilution of the Lemco. Further a smaller dose gave all the good effects without the primary inhibition. Various strengths, from 1 in 500

This experiment commenced at 12.15 p.m. and was stopped at 6.45. The three tracings on the 1st paper show a good result with Locke's solution without any dextrose. The tracings on the next two papers show the effect of Lemco. Unfortunately the stock of saline was finished and the 4th paper shows the result of the substitution of an inferior saline made up with rapidly distilled water.

to 1 in 10,000 were tried, but 1 in 4,000 to 1 in 6,000 appears to be the best strength. 1 in 5,000 was what was generally used, while stronger doses were given if the heart was contracting badly or had been inhibited by any artificial means, when it was as a rule a most marvellous restorative. It was found that stronger solutions than 1 in 3,000 usually had a bad effect,and those above 1in 7,500 had a slight effect only.

Boiling does not seem to affect the stimulating properties of Lemco, and alcohol does not dissolve them out, as the alcohol extractive was decidedly toxic. Incineration, supposedly destroying all the organic matter, left a residue which, when dissolved, caused a rapid fall in the rate of flow and in the size of the beats, an effect probably due to the potassium in the ash. Thus we may conclude that probably the stimulating substance is organic, but it is not proteid, as no proteid reaction can be got on testing Lemco, and the solution of Lemco is clear and remains so on boiling. Dialysation gave conflicting results. The non-diffusible part of Lemco seems slightly the more stimulating, but all the salts, which are mostly of potash, were of course in the diffusible part, and would powerfully inhibit any good effect it might have. The diffusible part however contained the substance that causes -presumably- the increase of flow, while the non-diffusible part did not in any instance cause a marked increase of flow, and in most cases did not materially affect it; so that it is probably right to conclude that the stimulating substance is diffusible.

It was found that the stimulating substance was

either chiefly in the upper part of the jar of Lemco or else that its good effect was more than counteracted by the inhibitory effect of the potassium salts which are in greater proportion at the bottom. Some jars of Lemco seemed to have almost no stimulating effect at all, but rather the reverse. I found it impracticable to follow this subject further than this.

INVESTIGATION OF THE BUNDLE OF HIS.

As long ago as 1883 Gaskell[23] showed muscular continuity between the auricles and ventricles of the frog and tortoise, and that the auricular impulse spread to the ventricles by passing over the muscular connection between these two parts. As far back as 1852 Stannius[24] by ligaturing the sino-auricular junction in the cold-blooded heart got a failure of transmission of the impulse from the sinus to the auricles.

In 1900 Gaskell[25] stated that- "the standstill after removal of the sinus is not permanent; the auricles and ventricles beginning to beat again after a time, at first slowly and then gradually quicker and quicker, until at last a good steady rate of rhythm is observed---if the cut is anywhere between the sinus and the ventricle, the same thing may be observed, the difference being that the primary standstill is longer the nearer to the ventricle the cut is made---- the part in connection with the sinus continues its regular beat; the separated part remains still for a variable time, and then, according to its inherent rhythmical power, develops a rhythmical beat of its own, the rate of that rhythm, when fully developed, and the length of time that the standstill lasts being corelated with the rhythmicity of the tissue."

It was not till 1893 that Stanley Kent[26] showed that this might similarly be applied to the mammalian heart, for he found here also a muscular continuity between the auricles and ventricles, which was contrary

23. Journ: of Phys: iv, p43. 24.
25. Schäfer's Text-book. ii, p175. 26. J: of Phys: xiv, p43

to what previous observers had thought they found. He described two kinds of muscular continuity. (1.) at certain points there is a direct continuity of the muscular tissue of the auricles and ventricles; one of the points is at the junction of the interauricular and inter-ventricular septa of the heart, which is the part now known as the auriculo-ventricular "bundle of His." (2.) A continuity by means of a net work of primitive fusiform muscular fibres imbedded in the fibrous tissue of the auriculo-ventricular rings of the heart. This second, or intermediate muscular continuity, Keith[27] has failed to find.

In the same year W. His, junior,[28] studying the embryonic heart found that the auricular impulse passed to the ventricle before nerves were developed in the heart, and concluded that the auricular impulses must pass to the ventricles via muscular tissue, as Gaskell had observed. He found that during development in the hearts of birds and mammals the muscular continuity disappeared everywhere except at the junction of the interauricular and inter-ventricular septa, where Kent had observed a connection, and that it was wrong therefore to suppose that muscular continuity between auricles and ventricles was broken entirely during development. He concluded,-(1.) That the a-v bundle was the sole path for the conduction of the auricular impulses to the ventricles, and that quite extensive destruction of the septum was of no avail, provided the a-v bundle was intact. (2.) He showed that cutting this bundle produced

27. Lancet, Aug: 11th, 1906. 28. Arbeiten aus der Med: Klinik zu Leipzig, 1893.

first an arhythmia and then a lasting allorhythmia with complete dissociation in the rate of auricular and ventricular contractions, both of which continued beating strongly but independently, and (3-) he found and accurately described the a-v bundle in man: its start from the right auricle near to the septum, uniting with the upper part of the ventricular septum, and its ending near the beginning of the aorta.

In 1899 His[29] suggested that irregularity in the rhythm of auricles and ventricles might be caused by a lesion of the a-v bundle.

In 1904 Retzer[30] and Braeunig[31] described the exact cause and the histological structure of the bundle. Max Humblet[32], Herring[33], and Erlanger[34] confirmed the existance of the a-v bundle, and its function experimentally, and proved that it is the only pathway for the auricular impulses to reach the ventricles;- if the bundle was partially cut through or compressed slightly, the impulse was delayed; if completely cut through or firmly compressed the auricular impulse was blocked, and so the ventricle would go on beating independently of the auricles.

Retzer[35] showed the bundle in macroscopic preparations in dogs, cats, rabbits, rats and man. In man it is about 18mm long, 2.5mm broad and 1.5mm thick.

29. Wiener Med: Blätter, 44, 1894. Centralblatt f: Phys: ix, p.469.
30. Archiv f: Anatomie und Phys: (Anatomische Abtheitung) 1904. p1.
31. Ibid: (Phys: Supplement) 1904 p.1.
32. Archives Internationales de Phys: 1, p.278.
33. Pfluger's Archiv, cviii, p.267. 34. J: of Exp: Med: viii, p. 8.
35. Loco Cit:

Langendorff[36] has ably summarised the literature of the a-v conducting system recently.

Tawara[37] found in mammals and pigeons that the a-v bundle begins in the neighbourhood of the anterior edge of the coronary veins and passes forwards on the right side of the auricular septum below the foramen ovale, lying close upon the a-v septum which passes obliquely from the left above to the right below. Just above the insertion of the median flap of the tricuspid valve, and before it makes its way into the a-v connective tissue septum proper, the a-v bundle forms a special knot, the thickening produced by a confused mass of muscle fibres. From this knot a process arises which penetrates the fibrous septum and runs along just below the pars membranacea septi, and dorsal to the muscular ventricular septum, dividing them into two main branches which pass obliquely downwards, one on either side of the ventricular septum under the endocardium. He states that no evidence has been found of any fusion of the fibres of the a-v bundle with those of the ventricular septum in its upper part, but rather both the right and the left main branch of a-v bundle, each enclosed in a connective tissue sheath of its own and completely isolated from all other muscles, pass a long way down the septum in order finally, and only in the lower third of the ventricular cavities within the so-called trabeculae, to enter the anterior and posterior papillary muscles. Until they get to the papillary muscles, the muscle fibres of each

36. Ergebnisse d: Phys: 1905, p.786.

37. Brit: Med: Journ: Oct. 27th, 1906.

main branch of the a-v bundle always lie under the endocardium; here however they divide into a large number of branches, some of which enter into the papillary muscles, while others pass on beyond them and follow the course of the small trabeculae to the parietal walls of the ventricles where they branch upwards and downwards under the endocardium lining, the whole inner surface of the cavities of the ventricles, to fuse everywhere with ordinary cardiac muscle fibres. In doing so the following peculiarity presents itself:- while the right main branch is fairly narrow and remains so until it enters the papillary muscles, the left main branch spreads out quickly in a fan-shaped manner, and continually increases in width during its downward course, and finally divides into two or more wide but extremely thin branches, of which the anterior one passes through trabeculae to the anterior papillary muscles, the posterior one similarly through trabeculae to the posterior papillary muscles.

He says the colour of the a-v bundle is greyish white, and paler than the ordinary muscle tissue of the heart, on account of the connective tissue sheaths in which the muscle fibres are enclosed. They are the fibres described by Purkinje in 1845 which are really branches of the a-v bundle. There is a smaller development of sarcoplasm in the fibres of the a-v bundle than in ordinary cardiac muscle fibre, thus more resembling embryonic muscle fibre, except that they differ from them in their peculiar arrangement, which is that the fibres of the a-v bundle all through their course tend to interlace and show reticulation, and also to fuse more with one another than does embryonic heart muscle. This

tendency to reticulation can be seen especially in the auricular portion of the a-v bundle between the mouth of the coronary vein and the entrance of the bundle into the fibrous septum, and the contrast to the ordinary muscle tissue adjacent renders distinction easy. This reticulation reaches its maximum in the "Knot" where the muscle fibres form a confused plexus, the meshes of which are filled with connective and adipose tissue. The moment the a-v bundle enters the fibrous septum, the fibres take a more parallel arrangement, and become richer in sarcoplasm, and the separate fibres get closer to one another and become enclosed in a common connective tissue sheath which separates them from the rest of the heart muscle, and ceases only when the fibres of the a-v bundle pass into the fibres of the cardiac muscle.

Erlanger[38] alone, and working with Hirschfelder[39] has studied the function of His' bundle and found that (1). compression of the a-v bundle alone will block the auricular impulses from reaching the ventricular; (2) as no nerve trunks are found here the transmission of the impulse must be muscular; (3) by using a screw clamp one arm of which curved to an L shape passed through the interventricular septum and behind the a-v bundle, he was able to so graduate his pressure that he could obtain all stages of heart block, such as 2 to 1, 3-1, 4-1, rhythms and so forth, up to complete heart block (4). When heart block is complete he found that the ventricles cannot be inhibited through the vagi. Hering[40] however contradicts this, and that (5) the duration of ven-

38. Journ: of Experimental Med: vol. viii, p8.
39. Amer: J: of Phys: xv. '05.'06. 40. Loco Cit.

tricular inhibition through the vagi, normally present in health, varies inversely as the degree of block, when the vagi are stimulated with maximal tetanising currents. (6) The accelerator nerves on the other hand continue to exert their normal influence over the ventricles even when the heart block is complete; and (7) that the moment when the block becomes complete the ventricles occasionally stop beating, and after varying periods resume again, accelerating gradually till their rate becomes the normal for complete heart block.

He states that when heart block is complete, and the ventricles at a standstill, the auricles go on practically undisturbed, the ventricles remaining fully relaxed. The stoppage of the ventricles occurs synchronously with the establishment of complete heart block, and the stoppage is longest when complete block is suddenly established out of a normal rhythm, but occasionally even under these circumstances stoppage was not obtained. Prolonged stoppage may also be obtained after long periods of a 2-1 rhythm. After even the very shortest of 3-1 rhythms the stoppage is very short. He describes two types of stoppage- the more common one is that in which the first interventricular interval is longest, the periods between the systoles thereafter gradually shortening up to normal ventricular rhythm; the second type is one in which the second intersystolic period is longer than the first, the third longer than the second, and so on for one, two, three, or rarely more contractions. The first type of stoppage is always much longer, but many variations occur for unknown reasons. He suggests that the cause of stoppage may be two-fold-(1) because

the normal physiological stimulus is cut off and the dormant inherent rhythmicity of the ventricles takes some time to develop its maximum efficiency. (2) because the clamp presses on, or irritates in some way, a peculiarly sensitive region, stimulation of which inhibits the ventricles alone[41].

In support of the first he finds that the ventricles stop the moment the heart block becomes complete, and also the relation of the duration of stoppage to the period of heart block at which it develops, shows that the slower 2-1 or 3-1 rate prepares the ventricles to take up independently their maximum inherent rhythmicity. The length of stoppage depends to some extent on the vigour of the heart, a weak slowly beating heart having a longer period of stoppage. Further, when complete block is established and the ventricles are contracting at their own rate, any mechanical stimulus applied to the a-v bundle never produces anything like stoppage of the ventricles, but one or more extra systoles. Moreover tetanic electric stimulation never produced stoppage of the ventricles in any stage of heart block or normal rhythm, but the ventricles responded with frequent powerful contractions, irregular in force and rhythm. Thus he concludes that the stoppage is due to the absence of stimuli, and not from inhibition.

Erlanger[42] found that neither mechanical nor electrical stimuli took any other path than the a-v bundle, for stimuli which caused extrasystoles of either the

41. See Hofmann: Nagel's Hand-buch der Phys: 1905. i.p226.
42. Loco Cit. p189.

auricles or the ventricles never crossed the auriculo-ventricular junction during complete block, but during partial block they frequently crossed this junction, and when conductivity was normal it was the rule for them to cross.

Heart block has been defined by Mackenzie[43] as "that condition where the stimulus for contraction, passing from auricle to ventricle by the muscular fibres joining the auricle and ventricle, is stopped or blocked on account of some defect in those muscle fibres." He says that a slight degree of block may depress the conducting function sufficiently to produce a prolongation of the interval between the auricular and ventricular contractions. A further degree of heart block will cause a ventricular systole to occasionally drop out from blockage of the stimulus at the a-v fibres. A further degree still will cause the ventricles to respond only to every second or third auricular impulse.

In a recent paper Erlanger[44] states that in man the auricular stimulus normally takes one-fifth of a second to reach the ventricles. Any lengthening in the auricular-ventricular interval ( the As-Vs period) produced by a slight degree of heart block, may be either due to a delay in the rate of transmission of the stimulus through the damaged tissue, or to such a diminution in the intensity of the stimulus, that a longer latent period occurs before the ventricle will respond to the slighter stimulus. Usually when such lengthening

43. Brit: Med: Journ: October 27th, 1906.

44. Ibid: (Erlanger).

of the As-Vs interval occurs, it is found that the intervals lengthen till finally one impulse fails to elicit any ventricular response: then, probably from the prolonged rest, the ventricle responds so readily to the auricular stimulus that the As-Vs interval is very short, lengthening again each time till there is another missed ventricular systole. Thus we may get any rate of rhythm from 10-1 to 2-1.

Lately Fredericq and Hering[45] using the excised and artificially perfused mammalian heart, have found that cutting the a-v bundle produces allorhythmia with complete independence of the ventricles, and they state that neither spontaneous nor artificially produced extrasystoles passed from auricle to ventricle, nor from ventricle to auricle. I have found however in many experiments that while conduction in the normal direction does not occur, frequently a ventricular systole will cause an auricular extrasystole provided that the ventricular contraction occurs when the auricular irritability is sufficiently restored.

Hering[46] states that when heart block is complete there is no compensatory pause proper, though the ventricular extrasystole may be longer or shorter than normal. Compensation is thus defined[47] - "the combined duration of the last (i.e. the cycle shortened by the extrasystole) spontaneous ventricular cycle and the extrasystole following it, plus the compensatory pause is

45. Report of Congress for Internat: Med: Munich. Semaine Medicale, May 9th. 1906. p223.

46. Archiv f: d: Ges: Phys: '05. cviii, p276.

47. Hofmann: Nagel's Handbuch d: Phys: '05. i, p241.

(within a small fraction of a second) equal to the duration of two spontaneous ventricular periods."

Erlanger[48] corroborates this statement of Hering's and states that ventricular extrasystoles are rarely more or less than normal by more than one-fifth of a second. Further, when heart block is complete, a ventricular extrasystole will never cause an auricular contraction, and an auricular extrasystole never causes a ventricular contraction. He finds that when heart block is partial there is practically never any compensation, and the duration of the ventricular extrasystoles differs little from the interventricular interval determined by the auricular contractions, and there is an obvious tendency for the same number of auricular beats to intervene between the extrasystole and the next uninfluenced ventricular contraction, as intervened between any two uninfluenced ventricular contractions. Erlanger further states[49] that in partial heart block ventricular extrasystoles never cause any auricular contraction, as indicated by the fact that rhythmic stimulation of the ventricles never affects the rate of the auricles. But auricular extrasystoles occasionally cause ventricular contractions in partial heart block, though this only occurs when the induced auricular systole immediately precedes that spontaneous auricular systole which would have stimulated the ventricle to contraction, and this phenomenon is more likely to occur when the heart is about to pass into a lower

48. Amer: Journ: of Phys: 1st May, 06.

49. With Hirschfelder, Amer: Journ: of Phys: xv, p196.

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state of heart block, than when the block is stationary.

He finds that occasionally when heart block is complete the ventricular systoles may so correspond with the auricular for a time as to simulate a state of partial block. An extrasystole will in such a case disturb the seeming sequence, though it must be remembered that an auricular extrasystole may momentarily increase the degree of block, and even make it appear to be complete, but in such a case the auricular ventricular sequence is soon restored. As a rule however, complete heart block can be easily recognised from simple measurement of the tracings. An increase in the auricular rate increases the degree of partial block. This is not due to fatigue of the bundle of His, but to each auricular impulse being weaker and therefore unable to excite a ventricular contraction through the partial heart block, for as soon as the normal interauricular interval occurs again with auricular systoles of normal strength we get the original sequence of ventricle after auricle. Occasionally however this recovery does not take place, looking as though the rapidity of the impulses might have fatigued the a-v bundle, but Erlanger thinks the explanation is that the stoppage or slowing of the ventricles causes them to distend with blood, and so to pull on the clamp and thus increase the pressure on the a-v bundle. In Table 1 of this paper it is to be observed that ventricular irritability increases gradually and slightly during partial and complete heart block, for when the ryhthm is normal a distance of 14cms between the primary and secondary coils is needed to

produce an extrasystole, while when a 2-1 rhythm was established 15cms were sufficient, and later 15.5cms, whereas when recovery took place to normal rhythm again 14cms were necessary. Later with a 2-1 rhythm a current at 15.5cms was all that was necessary, and on recovery of normal rhythm 14.5cms was the weakest stimulus that was effective. When complete block was established a current at 15.5cms was effective, but one at 16cms failed.

Erlanger enquires if subminimal stimuli increase rhythmicity in warm blooded spontaneously contracting ventricles, as Von Basch[50] found in cold blooded hearts, as his experiments give negative results. I have found that weak faradic stimuli do often become effective after varying periods of time, in some cases several seconds of steady stimulation elapsing before any response is obtained.

He states that in terrapin's ventricle, during partial block, a ventricular extrasystole excited by mechanical stimulation will cause an auricular contraction, but an auricular extrasystole will not cause a ventricular contraction. When a response occurs it is noticed that the delay in the response of the unstimulated part is greater when the wave is travelling in the direction in which the block had been either complete or partial, than when the wave is travelling in the opposite direction. With electrical stimulation however an auricular extrasystole may cause a ventricular contraction in partial or complete block. The conclusion

50. Archiv: für Phys: 1880, p283.

drawn is that an efficient stimulus will always elicit a maximal contraction, but that the impulse transmitted through the muscle may vary with the strength of stimulus, for when the block is partial a low auricular systole may fail to cause any ventricular response. Weak impulses seem to travel more slowly than strong ones, or else the latent period of contraction is longer with feeble than with strong impulses.[51] The strength of the stimulus needed to pass the block naturally depends upon the degree of block. The length of the interval between the auricular contraction and the ventricular response varies with the strength of the auricular impulse in relation to the irritability of the ventricles. The weaker the auricular impulse the longer is the latent period of the ventricles, their irritability continuing to increase till at last one of the auricular impulses added to the greatly heightened ventricular irritability causes an explosion. If the auricular contractions are still weaker complete block is established.

In the summary of these experiments Erlanger says[52] that in recent experiments he has never seen a premature ventricular contraction give rise to an auricular systole in partial block, and he assumes that the impulses caused by ventricular contractions are weaker than those caused by auricular contractions, and he states that in the normal heart conduction of a retrograde impulse through the a-v bundle is less rapid than the conduction of normal impulses.

51. See Engelmann: Archiv f: ges: Phys: 1895. lix, p.318.

52. Journ: of Exp: Med: '05. vii, p.710.

Cushny and Matthews[53] find that the period of an auricular extrasystole may be considerably longer than the normal interauricular period, and that occasionally after such an auricular extrasystole the normal interauricular interval may be gradually restored through several auricular cycles. When this occurs during partial heart-block, a lower degree of block may develop as the result of it, such as a 2-1 from a 3-1, or a normal from a 2-1, and may persist until the auricular rate becomes normal, or rarely for a somewhat longer time. Sometimes however a reduction in the degree of block follows an auricular extrasystole though the interauricular interval is unaffected. Later they state that after the refractory period irritability increases rapidly at first and then slowly to the maximum.

For doing my experiments on the "Bundle of His" in the rabbit's heart, I used Professor Brodie's apparatus for perfusion, arranging the apparatus so that the heart was uncovered and easily accessible. The bent pin attached to the light aluminium lever was fixed in the right ventricle near the apex while another pin, leading over a small very easily moving pulley to another light lever of the same length, was fixed to one of the auricles. Thus by starting with the two levers so arranged that their writing points were vertically above one another, it was possible to obtain tracings giving any variations in rhythm, rate or in the length of the As-Vs interval. If the two writing points do not start vertically above one another due allowance must be made

53. Journ: of Phys: '06. xv, p. 226.

in the subsequent calculations. The upper tracing was that recording the auricular systoles, the lower the ventricular contractions. Between this and the base line a time marker giving 1/20 of a second was usually inserted, so that all variations could be recorded in fractions of a second as well as in fractions of the cardiac cycle. In many cases however I discarded all time measurements, expressing the variations in fractions of the complete auricular cycle as this gives the true proportion of the As-Vs interval, whereas the time measurements are constantly varying.

Usually the right side of the heart was the one from which the Bundle of His was approached, as it was found that not only was the section of the bundle more easily accomplished from this side, but also the right ventricle is easier to incise and retract, on account of its thinner walls, without spoiling the tracing and having continually to stop to readjust the levers in height and in their vertical relations to one another. Several experiments were however done on the left side, but it was found necessary to make a considerable incision to secure efficient retraction of its thick walls, and generally also it was necessary to divide the auriculo-ventricular sulcus with its vessels in order to get at the a-v bundle properly. I found it practically impossible to reach the a-v bundle through the left auricle alone even when the whole of this was removed, having invariibly to divide the auriculo-ventricular sulcus. I tried this left side route in order to try the effect of section of the different branches of the left division of the a-v bundle, and also the left division before

it branches. It is always advisable to ligature all coronary vessels of any magnitude before section, as otherwise a considerable amount of saline might be lost.

It is remarkable how much cutting about an artificially perfused heart will stand without showing marked disturbance, when it has settled down to its work. On one occasion all the right side of the heart was cut away and still a fair tracing was obtained. On another both ventricles were almost entirely removed but the septum continued to give a fair record. In yet another case all the right ventricle and the whole of the septum were removed and finally the ventricles were left hanging by a portion of the L.V. about 5mms wide, and yet fair contractions continued, considering what a little saline fluid could possibly have reached the tissues after such extensive section.

It makes no discernable difference cutting any of the ultimate branches of the bundle. I have divided both the descending and the anterior divisions of the left branch of the a-v bundle, as it emerges through the interventricular septum, but noticed absolutely no change at all except a distinct lengthening of the As-Vs interval. Similarly I cut through the left division before it branches (so far as anyone has yet found), but obtained no result though I cut almost through the thickness of the septum. I have also tried dividing the right division, first of all in its ramifications and then closer and closer to its separation from the left division, but all seemed to be absolutely of no avail, the ventricles going on responding to the auricular impulses undisturbed. This seems entirely to contradict

the usual view that the fibres of the a-v bundle do not fuse with those of the septum in its upper part, but continue enclosed in a sheath a long way down the septum uniting only in the lower third, as otherwise it would have been possible by dividing all the main branches to produce the same effect as by section of the a-v bundle itself either before it reaches the pars membranacea septi, or just before its division into right and left. This I never found it possible to do; for unless the bundle was divided just as high up as one could go without injuring the cusp of the aortic valve, that is to say before, or just at its division, one might divide the whole septum across, and further carefully dissect practically every scrap of muscular tissue away from the pars membranacea and the fibrous tissue at the root of the aorta, and yet get only a very partial condition of heart block. I have one heart preserved in spirit where this dissection was carefully done, and not a scrap of septum seemed to remain, and yet complete heart block was not produced. It seems as though there were some other path of conduction which can only be divided by an incision at, or before the bifurcation of the a-v bundle.

Occasionally one comes across rabbits' hearts which have an abnormally large membranous portion of the septum, and in these the a-v bundle seems to pursue an abnormal course, or to divide prematurely, or else its anatomical relations are masked; for division at the usual successful spot produces no heart block, and it is not till the division is performed high up on the interauricular septum while the fibres of the bundle are in

the auricular cavity, that heart block is obtained; and great care has to be exercised in doing this, as frequently the aortic valves commence to leak seriously, and thus render the experiment practically useless.

In one experiment I carefully separated the right from the left ventricle right up to the auricles, and placed a pin with lever attached in the tip of each ventricle, and tried to block one without the other, but found that the most careful sections of the left and right branches separately produced no block, and, as in every other experiment, finally one snip penetrating the entire thickness of the septum blocked both ventricles simultaneously.

I found further that so long as a minute part of the a-v bundle was left undivided, although it immediately appeared after section as though complete block had been obtained, yet recovery would almost invariably take place, generally to normal rhythm. This might take a considerable time, as though enough stimulus could not pass the block to stimulate the ventricles to respond until their irritability and inherent rhythmicity had developed sufficiently to cause the auricular impulses to be efficient. For, seeing that the blades of a very fine pair of scissors were thrust in and then smartly brought together, or a sharp knife was used, there cannot have been sufficient compression of the bundle without division to explain this phenomenon; for the mere insertion of the scissor blades, while causing arhythmia from the mechanical stimulation, never produced any heart block, and therefore since all between the blades was irremediably divided this recovery cannot be account-

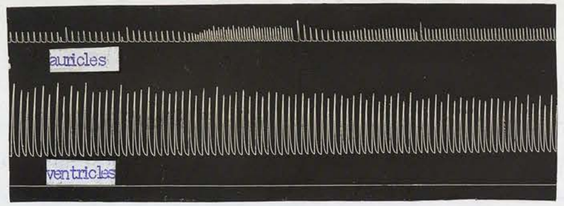
ed for by temporary pressure producing transient shock.

Further I was unable to prove that any part of the bundle that was cut affected any one part of the ventricles. In one or two experiments it did seem as though one ventricle were more affected than the other, and on one or two occasions as though part of a ventricle were affected, but it was practically impossible to be certain of the point, and different onlookers of experience gave quite different opinions as to the result obtained. Thus I infer that as long as a small part of the thickness of the a-v bundle is still in-tact every part of both ventricles will respond to the auricular stimuli, and that this may be due to the extreme reticulation of the fibres and their tendency to fuse one with another, so that every bundle of muscle fibres may be said to have an universal distribution. Moreover apart from actual compression, such as Erlanger used, any part of the a-v bundle uncut and uninjured is capable of performing almost the entire function of the whole bundle, and that the whole bundle must be cut across, or damaged by compression, for even a partial state of heart block to remain for any length of time. For often in these experiments snip after snip was given to the bundle without any sign of heart block except lengthening of the As-Vs interval, till finally a touch with the edge of a knife, which could not have cut more than .2 of a millimetre deep has produced total block. Possibly the left and right branches of the a-v bundle are not confined in their distribution to their own side of the heart, but supply both ventricles, for it looks as though auricular impulses were capable always, when one of the

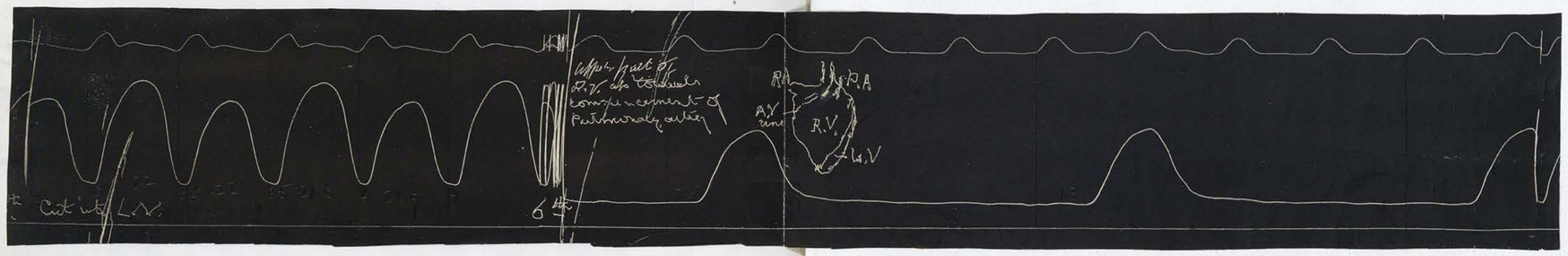
two primary branches was divided, of reaching both ventricles simultaneously through the other uninjured branch

With regard to the more exact details of the procedure usually followed- The heart was suspended from the cannula with the right ventricle facing me; I then passed a ligature round the root of the descending branch of the right coronary artery. This I tied tightly, and then incised the right ventricle about 2mm from the auriculo-ventricular sulcus parallel with the sulcus and running upwards anteriorly to the root of the pulmonary in the shape of a very obtuse angled L. The flap of the right ventricle was now retracted anteriorly, and the auriculo-ventricular sulcus lightly hooked upwards and backwards. The traction must be gentle, or else the levers are disarranged in their relative positions. The septal cusp of the tricuspid valve was now excised, and the right hand blade of a fine sharp-pointed pair of scissors inserted into the junction of the muscular and membranous portions of the septum, where a line perpendicularly down the centre of the aorta, as the heart is hanging, cuts this junction. The left hand blade is inserted, not more nor less than 2mms posteriorly along the same upper edge of the muscular part of the septum, and making sure that both blades transfixed the septum (usually 1-2mms thick) they are rapidly and firmly brought together, and almost invariably total block is produced. The incision thus produced runs slightly downwards and backwards.

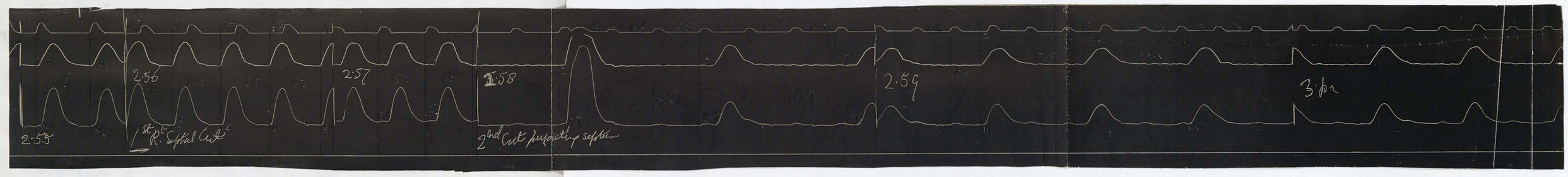
Should however the pars membranacea be abnormally developed, it is necessary to cut more upwards and backwards posteriorly to the aortic perpendicular line, in




A-v bundle cut - absolute allo-rhythmia - acceleration of the auricular rate does not affect the ventricles.




Tracing before and after section of the a-v bundle.
Permanent Dissociation.




Tracing of auricles, left ventricle in the middle and right ventricle next to the base-line.
Complete and permanent dissociation.

did not contract spontaneously again, though they responded readily to mechanical or electrical stimulation, the auricles continuing to beat vigorously and at their normal rate all the time. This was very unusual and difficult of explanation.

The normal As-Vs interval averages about 1/7 of the cardiac cycle or roughly between 1/9 and 1/10 of a second. Incising the ventricles generally produced a temporary shortening of the interval, sometimes up to 1/10 of the cycle, and section of the auricles produced a still greater shortening. Section of a part of the a-v bundle invariably lengthens the As-Vs interval: if the cut is slight the effect is very transient, but when the section is almost complete the interval may be lengthened to as much as ¼ of the cycle, but always tends to recover nearly to normal.

In these experiments partial block was almost invariably temporary only, so that the length of the As-Vs interval in different states of block could not be very well studied. But it is seen that with a 2to 1 rhythm the rate of conduction is generally normal when this state of block has been established some little time, though at first it is always slower. When a 2 to 1 rhythm passes back to normal, the As-Vs interval usually lengthens from about normal (1/7 of the cycle)to 1/5, or even ¼ of the cycle, showing that when the ventricles are responding to every stimulus either conduction is slower or a longer latent period occurs than when only every second stimulus is effective. When however the normal rhythm has been established a minute or two conduction usually returned to nearly normal.

On one occasion a 4 to 1 rhythm was found to occur for a time, with an As-Vs interval of ¼ of the cycle. On another, with a 3 to 1 rhythm the interval was as much as 1/3.

At the commencement of any state of heart block the As-Vs interval is at first long and gradually shortens almost to the normal. A lower state of heart block then develops with a long interval, which again gradually shortens nearly to the normal, when a lower state or normal rhythm may occur, also with a long interval to start with shortening nearly to the normal.

After section of the a-v bundle in many experiments the ventricular contractions excited auricular extrasystoles, but there was no conduction present from auricle to ventricle, the ventricles continuing at their own independent rate. In these cases the Vs-As interval is usually nearly half as short again as the normal As-Vs interval.

In one experiment where the a-v bundle was divided there was complete stoppage of the ventricles for three minutes when a single contraction occurred, after which no ventricular contraction appeared again for 18 minutes. The ventricles then resumed at a 2-1 rhythm with an As-Vs interval of 1/7. Two minutes later there was normal rhythm with an interval of from 1/5 to ¼, but two minutes later there was again complete independence with irregular ventricular systoles and no auricular extrasystoles. 8 minutes later there was again normal rhythm with an interval of 1/6, 4 minutes later the ventricles ceased contracting, resuming again in 1 minute at normal rhythm with an interval of 1/6. 2 minutes later

there were again no contractions of the ventricles but within two minutes there was again normal rhythm with an As-Vs interval of $^1/_5$ of the cycle. This alternation kept on for more than an hour longer and seems inexplicable unless the extensive destruction of the ventricle and septum had rendered their contractile powers too feeble, but then one would have expected every other or every third auricular stimulus to elicit a ventricular response and to have had a state of partial block, instead of this alternating normal transmission followed by long ventricular silences. It seems as though conduction were intermittent but that when it occurs it is perfect enough to allow of normal rhythm with only a slightly lengthened As-Vs interval. To what this intermittency was due it is impossible to say.

In a second experiment it was found that when the right ventricle was incised conduction was reversed, the ventricles leading by an interval of 1/5.7, but recovery rapidly occurred to normal conduction with an As-Vs of $^1/_{12}$. The first septal cut was superficial and caused the ventricles to again take the lead with a Vs-As of $^1/_{3.4}$, but recovery rapidly took place and the As-Vs was then $^1/_5$. The second cut caused absolute allorhythmia after a pause of about 2 seconds followed by a big contraction. In this experiment a separate tracing was taken of the left and right ventricles, and when allorhythmia was established the left ventricle seemed to lead the right by a small fraction varying from 0 to $^1/_{25}$. No auricular extrasystoles occurred in this experiment.

In a third experiment a cut at the a-v bundle caused stoppage of the ventricles for several beats,

followed after a single big contraction by normal rhythm with an As-Vs interval, which at first was practically non-existent and then slowly lengthened to about 1/30. The next cut caused stoppage of the ventricles for 6 minutes, after which they slowly and at first irregularly resumed their own rhythm, but auricular extrasystoles occurred in response to the ventricular contractions, the Vs-As interval being 1/14.5. The extrasystoles were almost identical in length with the normal auricular periods and there was no attempt at compensation. The Vs-As intervals gradually increased to 1/7. The extreme shortness of the As-Vs interval after the first cut is very remarkable, as is also the primary shortness of the Vs-As interval after the second cut.

In a fourth experiment in which after section of the bundle auricular extrasystoles were found to follow many of the ventricular contractions the Vs-As was 1/6. Compensation was not perfect, the lengths of the shortened spontaneous cycle plus the extrasystole only occasionally equalling the sum of two normal cycles. But this interesting fact was observed that (1) when the ventricular contraction occurs 4/33 before the next auricular systole is due, the next auricular systole follows normally, as it is due at least 1/33 before the ventricular impulse reaches it- it is thus too late to cause an extrasystole. (2) When the ventricular systole occurs 7/30 before the next auricular systole is due it excites an extrasystole 5/30 later, that is to say 2/30 before it was due. The extra systolic cycle is 2/30 longer than normal so that compensation is perfect. (3) When the ventricle contracts 8/29 before the next auricular systole

is due, it induces an auricular extrasystole $^{5}/_{29}$ later, that is $^{3}/_{29}$ before it is due. The extrasystole is only $^{31.5}/_{29}$ or $^{.5}/_{29}$ short, so that compensation is practically perfect. (4) When the ventricular contraction occurs $^{11}/_{34}$ before the next auricular systole, the extrasystole follows $^{6}/_{34}$ before it is due and compensation is perfect all but $^{3}/_{34}$. (5) When the ventricular contraction occurs $^{18}/_{30}$ before the next auricular systole is due, it induces an extrasystole $^{6}/_{30}$ later or 6 early. The extrasystole is $^{33}/_{30}$ or $^{3}/_{30}$ short of perfect compensation. (6) When the ventricular systole occurs $^{23}/_{34}$ before the next auricular systole is due it excites an auricular extrasystole $^{7}/_{34}$ later or $^{16}/_{34}$ early. The extrasystole is here only $^{38}/_{34}$ or 12 short of compensation. (7) When the ventricular systole occurs $^{27}/_{34}$ before the next auricular systole is due, its impulse reaches the auricle probably $^{20}/_{34}$ before the next contraction is due and falls within the refractory period and so excites no response. We see that the earlier an extrasystole is excited, the longer is the Vs-As interval, as excitability has had less time to recover.

In a fifth experiment after the left division of the a-v bundle had been divided, the heart was turned round and the right ventricle cut open, when without warning dissociation occurred, there being no ventricular activity for several seconds. The cause may have been that the auricles were accidentally stimulated to a more rapid rate, though this was not noticed, and thus the temporary total block occurred. Or else during the opening of the right ventricle the remaining fibres of the bundle were so pulled upon as to produce temporary

block. Within 2 minutes normal rhythm had returned. The a-v bundle was then cut through at its bifurcation, complete dissociation occurring, with the ventricles beating at a rate 1/3 that of the auricles. Five minutes later the following condition occurs:- A 1 to 1 rhythm is present but the As-Vs interval seems to be nearly ½ the normal cycle, and each ventricular systole causes an auricular extrasystole at 1/11 of the cycle, while compensation is nearly perfect. This is however an exceptional 2 to 1 partial heart-block, because the inter-ventricular cycle corresponds to two normal cycles, but every ventricular systole excites an auricular extrasystole which causes it to appear like a 1 to 1 rhythm. The measurements are- 20 + 48.5, and 20.5 + 48, while the normal cycle measures 35, so that compensation is only 1.5/35 short of perfection. A further cut this time produces real and lasting dissociation, the ventricles continuing independently at about ¼ the auricular rate.

In a sixth experiment, after the a-v bundle had been divided and the ventricles had resumed their own independent rhythm, a reversed conduction developed with nearly every second ventricular contraction producing an auricular extrasystole, but with no sign of any ventricular response to the auricular contractions. The auricular rate was 78 per minute and the ventricular 36, so that this 2to 1 rate was not absolute and the relative sequence of the auricles and ventricles was constantly varying. The Vs-As interval was of about the same length as the normal As-Vs interval. Any ventricular systole that did not fall in the auricular refractory

period caused an auricular extrasystole. As in the experiment to be described next, we find that the ratio of the As-Vs interval to the normal inter-auricular interval has a distinct relationship to the difference in the heights of the auricular extrasystole and the normal auricular systole following, and also to the ratio of the long pause of the auricular extrasystole to the normal inter-auricular interval. Thus we find that when $\frac{As-Vs}{As-A's}$ (taking As-A's as the normal inter-auricular period) is .25 or less, the difference in the height of beat is 1 millimetre or less, and the $\frac{A''s-A'''s}{As-A's}$ (taking A''s-A'''s as representing the long auricular extrasystole) is less than .1. Further that when $\frac{As-Vs}{As-A's}$ is .76 or more, the difference is again 1 mm or less, and that again the $\frac{A''s-A'''s}{As-A's}$ is less than .1 . The maximum difference in the heights of the beats occurs when $\frac{As-Vs}{As-A's}$ is about .4 or ranging from .35 to .45 . Either above or below this there is a rapid fall in the difference in the heights of the beats which at its maximum is 4.5 mm. The same holds true of the $\frac{A''s-A'''s}{As-A's}$ which reaches a maximum of .2 when $\frac{As-Vs}{As-A's}$ equals .427, and is .15 when $\frac{As-Vs}{As-A's}$ = .388, .18 at .455, and .16 when $\frac{As-Vs}{As-A's}$ = .531 . Above and below this proportion the ratio gives less than .15, and diminishes towards either extreme gradually. There is not a regular ratio between the As-Vs and the Vs-As intervals, though roughly it may be stated that the shorter the As-Vs interval the longer will be the time elapsing before the auricle responds to the ventricular contraction; and the longer the As-Vs the more quickly will the auricle follow the ventricular contraction. Absolute compensation was

not present, but the extrasystole added to the preceding normal auricular systole were about 1/3 of a cycle shorter than the sum of two normal periods.

I append the tabulated results here obtained:-

| $\frac{As-Vs}{As-A's}$ | Difference in heights of beats. | $\frac{A''s-A''s}{As-A's}$ |
|---|---|---|
| 0.084 | 0.5 mm | 0.02 |
| 0.167 | 0.1 | 0.00 |
| 0.242 | 0.4 | 0.01 |
| 0.388 | 4.4 | 0.15 |
| 0.399 | 4.5 | 0.17 |
| 0.427 | 4.5 | 0.20 |
| 0.455 | 3.6 | 0.18 |
| 0.531 | 1.8 | 0.16 |
| 0.534 | 3.3 | 0.13 |
| 0.643 | 0.2 | 0.13 |
| 0.763 | -2.9 | 0.10 |
| 0.848 | -2.5 | 0.05 |
| 0.907 | -1.8 | 0.04 |

Division of all but half the left ventricle still failed entirely to check this reversed conduction.

In a seventh experiment after the a-v bundle was divided there was no ventricular contraction for an hour and a quarter, after which the ventricles gradually quickened up to a rate of 1 to 4 auricular systoles, with complete absence of auricle to ventricle conduction, but with a great number of auricular extrasystoles caused by the ventricular contractions, the Vs-As being about 1/12 of the normal cycle. On the next sheet the measurements and ratios here obtained will be found tabulated. As in the last experiment there is a definite relationship between the ratio of the As-Vs interval to the normal inter-auricular cycle, and the difference in the height of the beats, and also to a great extent the ratio of the extrasystole to the normal inter-auricular cycle.

| As-Vs / As-Vs | Diff:of Hts: in mms. | As-As / As-As | As-Vs / As-As | Diff:of Hts: in mms. | As-As / As-As |
|---|---|---|---|---|---|
| .00 | 0 | .982 | .73 | 1.1 | 1.07 |
| .00 | .1 | 1.00 | .74 | .9 | 1.04 |
| .01 | 0 | 1.00 | .75 | .1 | 1.03 |
| .06 | .1 | 1.02 | .76 | .8 | 1.02 |
| .17 | .1 | .991 | .76 | .9 | 1.03 |
| .20 | .1 | 1.03 | .77 | .9 | 1.05 |
| .21 | 0.0 | 1.02 | .78 | .7 | 1.04 |
| .21 | 5.5 | 1.02 | .78 | 1.0 | 1.055 |
| .22 | -0.1 | 1.02 | .79 | .2 | 1.06 |
| .25 | .1 | 1.04 | .80 | .8 | 1.04 |
| .26 | 5.6 | 1.95 | .80 | .7 | 1.03 |
| .28 | 4.7 | 1.09 | .81 | .2 | 1.06 |
| .28 | 4.7 | 1.08 | .82 | .7 | 1.01 |
| .30 | 5.1 | 1.08 | .82 | .1 | 1.04 |
| .32 | 4.8 | 1.09 | .83 | .9 | 1.05 |
| .33 | 4.9 | 1.11 | .83 | 0 | 1.03 |
| .35 | 4.0 | 1.07 | .83 | .8 | 1.045 |
| .36 | 3.1 | 1.036 | .86 | .2 | 1.04 |
| .37 | 3.8 | 1.105 | .87 | -.1 | 1.03 |
| .38 | 4.1 | 1.13 | .88 | .3 | 1.00 |
| .39 | 3.5 | 1.07 | .88 | -.4 | 1.04 |
| .40 | 4.0 | 1.10 | .96 | -.7 | 1.00 |
| .41 | 2.9 | 1.05 | 1.00 | -.5 | 1.02 |
| .43 | 3.1 | 1.08 | 1.00 | .1 | 1.02 |
| .43 | 2.9 | 1.08 | | | |
| .43 | 2.9 | 1.035 | | | |
| .45 | 3.5 | 1.09 | | | |
| .45 | 2.9 | 1.06 | | | |
| .50 | 2.5 | 1.04 | | | |
| .50 | 2.2 | 1.06 | | | |
| .51 | 2.7 | 1.02 | | | |
| .51 | 2.4 | 1.06 | | | |
| .55 | 2.0 | 1.043 | | | |
| .56 | 4.6 | 1.09 | | | |
| .56 | 2.1 | 1.02 | | | |
| .56 | 2.2 | 1.09 | | | |
| .56 | 2.2 | 1.09 | | | |
| .56 | 2.3 | 1.11 | | | |
| .57 | 2.2 | 1.12 | | | |
| .58 | 2.3 | 1.045 | | | |
| .58 | 2.7 | 1.06 | | | |
| .59 | 2.2 | 1.06 | | | |
| .61 | 1.4 | 1.07 | | | |
| .61 | 1.2 | 1.04 | | | |
| .62 | 1.5 | 1.04 | | | |
| .62 | 1.2 | 1.03 | | | |
| .64 | 1.3 | 1.10 | | | |
| .66 | 1.5 | 1.02 | | | |
| .66 | 1.8 | 1.06 | | | |
| .67 | 1.0 | 1.035 | | | |
| .67 | 1.1 | 1.065 | | | |
| .69 | 1.5 | 1.06 | | | |
| .69 | 1.1 | 1.034 | | | |

Thus we see that when $\frac{As-Vs}{As-A's}$ (taking As-A's as the normal inter-systolic period) is between 0.25 and 0.35 we get the maximum differences in height of beats of the extrasystole and the one following, also the $\frac{A''s-A'''s}{As-A's}$ (taking A''s-A'''s as the long extrasystolic period) is at its maximum. As the $\frac{As-Vs}{As-A's}$ increases there is a gradual diminution in the differences in the height of the beats, and also a diminution, though not so marked, in the $\frac{A''s-A'''s}{As-A's}$.

The Vs-As interval varies slightly, but seemingly not in any constant relationship to the As-Vs interval or to the extrasystole.

I measured this heart carefully. The right ventricle from the apex to the commencement of the pulmonary artery was 23 mm. From apex to root of aorta 21mm. The broadest part of the right ventricle measured 16mm. The tricuspid orifice 9mm. From the root of the aorta across the infundibulum was 7mm. The total length of the incision in the septum was 2mm, and the thickness of the septum 1.3 to 2mm.

Now this is a state of complete and lasting heart-block, and yet there is reversed conduction always occurring when the ventricular systole does not fall in the auricular refractory phase. This does not agree with the results obtained by Fredericq and Hering (p.50) that when block is complete with independence of the ventricles spontaneous extrasystoles do not pass from ventricle to auricle; nor with those of Erlanger (p.5) that when heart-block is complete or partial a ventricular extrasystole will never cause an auricular contraction.

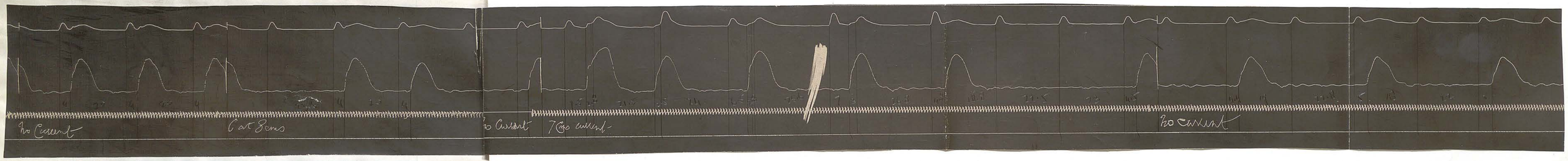
Mechanical stimulation of the lower cut end of the a-v bundle produces one or more ventricular contractions, and has produced as many as 15 to 20 rhythmic contractions of greater amplitude than normal, without affecting the auricular rate.

Mechanical stimulation of the ventricles during stoppage produced one or two contractions according to the strength of the stimulus. The contractions are slow-

er than normal. Repeated rhythmical mechanical stimuli on one occasion started a series of about half a dozen regular ventricular contractions, and one of them excited an auricular extrasystole after a Vs-As interval of 1/3.3 of the cycle, the shortened spontaneous cycle and the extrasystole measuring together only 1/44 short of absolute compensation.

Electric stimulation produces varying effects according to its strength. A weak current applied to the ventricles may immediately produce a single contraction only, or a single contraction may occur after several seconds stimulation. A strong current will produce any number of systoles up to tetanus.

In a normal heart, Faradic stimulation sufficient to produce a slow ventricular clonus, usually needs the secondary coil to be between 2 and 3 cms. nearer the primary circuit when the current is passed through the ventricular walls, than when the current is passed through the intact a-v bundle; that is to say that the uninjured a-v bundle seems 2 to 3cms more sensitive than any other part of the ventricles. When however the a-v bundle has been divided, its electrical excitability seems to be greatly lowered, and in some cases to be almost entirely abolished, for the full strength of current often failed to stimulate the cut a-v bundle, though a current with the two circuits 8cms apart would stimulate the ventricles. This marked lowering of excitability was found sometimes to extend all over the interventricular septum, with the exception of its extreme edges where the lateral walls of the ventricles join it; here the excitability was about the same as that of the ventri-




Reversed conduction, with uncut a-v bundle.
The Vs-As interval is about half the normal As-Vs.
The current at 8 cms between the primary & secondary circuits blocks one auricular impulse, then there are two normal ventricular contractions, and lastly a blocked auricular stimulus. After the period of stimulation at 7 cms. a 2-1 rhythm is established for a time, probably from fatigue of the a-v bundle, and the $A_s$-$V_s$ interval is lengthened.

cular walls.

Stimulation of the upper end of the cut a-v bundle produces auricular excitation, and excitability does not seem to be diminished in this direction.

The current for electric stimulation was generated by two Daniell's cells, whence the current ran through a switch to an induction coil, from there to a time-marker giving 1/20 of a second, and so back to the batteries. Two minute pins, attached to fine electric wires, were used as the electrodes; one was inserted at each edge of the a-v bundle high up near its bifurcation. Two similar electrodes were inserted at any point in the ventricles outside the a-v bundle, so that by means of a two-way switch either the bundle or the ventricles could be stimulated at will, and thus their excitability compared.

A current that passes through the uncut bundle and fails to stimulate the ventricles, does not appear to affect the length of the As-Vs interval as a rule. On one or two occasions however it did seem to produce a temporary block, for the ventricles ceased beating for a short time. Any current that stimulated the ventricles to clonic activity, abolished during that period all auriculo-ventricular sequence, but most of the ventricular systoles excited auricular extrasystoles.

When the a-v bundle was uncut, a current that excited ventricular contraction, produced a reversed conduction with a rate about half that in the normal direction. During clonus however the reversed rate varies considerably, and may even occasionally be longer than the normal As-Vs interval.

After section of the a-v bundle, an efficient electric stimulus that excites an auricular extrasystole, causes a reversed conduction which is sometimes about the same in rate as that in the normal direction, but is usually rather more rapid and varies somewhat with the strength of the stimulus. When the a-v bundle was first divided, and then its lower end stimulated so as to produce a slow ventricular clonus which excited auricular extrasystoles, it was noticed that when the inter-auricular cycle was as long as 9/10 of the normal, the Vs-As interval was shortest, averaging 1/9 of the cycle. When the cycle was 8.5/10 of the normal, the Vs-As interval was 1/8.3 of the cycle; when the cycle was 6/10 of the normal, the Vs-As interval was 1/6.6 of the cycle.

March 1907.