



*Professor Keimel,
With Dr. Fraser's compliments.*

THE

19

TREATMENT OF ANEURISM
BY ELECTROLYSIS.

By JOHN DUNCAN, M.A., M.D., F.R.C.S. Ed.

WITH

AN ACCOUNT OF AN INVESTIGATION

INTO

THE ACTION OF GALVANISM ON BLOOD
AND ON ALBUMINOUS FLUIDS.

By THOMAS R. FRASER, M.D., F.R.S. Ed.,

ASSISTANT TO THE PROFESSOR OF MATERIA MEDICA IN THE UNIVERSITY OF EDINBURGH.

READ BEFORE THE MEDICO-CHIRURGICAL SOCIETY, 1ST MAY 1867.

EDINBURGH: PRINTED BY OLIVER AND BOYD.

MDCCCLXVII.

REPRINTED FROM THE EDINBURGH MEDICAL JOURNAL FOR AUGUST 1867.

ELECTROLYSIS IN ANEURISM.

PART I.

IN the spring of last year I read before the Medico-Chirurgical Society a paper on the Galvano-Puncture of Aneurism, and in it I related the history of an aortic aneurism, for which that treatment had been adopted.¹ I have now to record a somewhat similar case which terminated unsuccessfully, and one of cirroid aneurism of the scalp more fortunate in its result.

In March 1866, Dr Macgregor of the Barnhill Hospital, Glasgow, kindly asked me to examine a patient under his charge, with a view to the application of electricity. This patient, James Lee, fifty-two years of age, robust and well-made, was at one time in the army, but for seventeen years had acted as a gentleman's servant. He was admitted to the hospital on the 19th of March 1866, principally on account of an ulcer of the leg, which speedily healed under treatment. He stated that about a month before admission he discovered pulsation in the upper part of his chest, and that soon afterwards pain and swelling supervened, which, as well as a gradually increasing debility, compelled him to give up work.

When I saw him in June, this tumour, evidently an aneurism of the aorta, projected about two inches from the surface of the chest; was nearly round, and had a diameter of more than four inches. It was situated to the right of the sternum, on the level of the second and third ribs. The pulsation in it was strong throughout, and the aneurismal bruit loud and distinct. The patient suffered occasionally from pains in the tumour, shooting also down the right arm and up the right side of the head and neck. He had no difficulty in swallowing, but when lying on his back had a little

¹ Edinburgh Medical Journal, April 1866.

embarrassment of the respiration, and a good deal of laryngeal cough. The respiratory murmur was pure, with the exception of slight sibilus in the right lung posteriorly.

On account of the rapid increase of the tumour, the apparently small amount of coagulum in it, and the comparatively slight disturbance of neighbouring organs, I agreed with Dr Macgregor that the tendency to death was by external hæmorrhage, and we determined to attempt its delay by means of electricity.

The operation was therefore performed on the 21st of June 1866. The patient was placed on his back, and two needles were introduced from the outer side, parallel to each other, and about one inch apart. The positive needle, which was coated with gutta-percha, traversed the centre of the tumour; the negative, coated with glass, was placed a little lower. The electric circle was closed at 11.58 A.M. by means of a key interposed in the wires.

Six minutes after its closure he began to complain of pain, the skin seemed to grow more tense, and a slight tympanitic note could be elicited by gentle percussion on the tumour. All these signs of galvanic action became more marked as we continued the application. He at first described the pain as a "burrowing," a "boring," a "weight on the chest;" but three minutes before the end of the operation he said it had become acute and burning. The electric current was stopped at 12.15, seventeen minutes after its commencement, as slight lividity began to show itself round the negative needle, the glass coating of which had cracked in introduction, and slightly separated from subsequent movements. On withdrawing the needles, a portion of the gutta-percha which covered the positive was left in the wound. It had become softened during the operation. Then also a quantity of gas escaped into the cellular tissue, and crepitated on pressure.

The patient passed a restless night—partly on account of another sufferer in the ward. Next morning his pulse was 100, and he had little appetite for breakfast. From the escaped gas and consequent œdema, the tumour measured nine inches from right to left, but was not much, if at all, changed from above downwards. The skin was tense and tender to the touch, so that he could not bear even slight pressure without a sickening sensation. The pulsation was not very notably diminished. The same evening the swelling began to decrease, and the pulse to fall; and by the 24th, the tumour was much as before the operation, retaining only an oval shape. The patient stated that he felt relieved, and especially that the shooting pains in arm and head were very greatly better. He complained, however, of uneasiness at the sternal edge of the tumour.

On the 27th, a small abscess formed at the point where the positive needle had penetrated, and an insignificant dry slough at the other puncture began to separate. Under a light poultice the slough came away and the abscess discharged itself; and, by the 29th, the aneurism had completely resumed its original shape and size.

From the 7th to the 24th of July it slowly increased again, becoming more uneven on the surface, while the pains returned to their former severity. The increase was mainly upwards, and the lower part felt moderately hard, and had a less distinct pulsation than the upper. On the 24th, I extracted, by a minute incision, a little ball of gutta-percha, which had remained under the skin since the operation, and had become encysted. I also repeated the galvanism, using needles coated with vulcanite, and inserting them in the upper or enlarging portion of the tumour. A battery of six Bunsen's cells was used (four had been the former number), and the action was continued for twenty minutes. It was stopped because the patient began to complain of a feeling of faintness, though the pulse did not diminish in force. The train of occurrences was nearly as has been already described,—rapid swelling with rapid subsidence of the same, pain on pressure and tension, relief, but not so marked as before, from the shooting pains, and for a short time a seeming arrest of growth. Dr Macgregor notes on the 25th, the day after the operation,—“Tumour of an oval shape; pulsation very slight, and more like the general lifting of the whole bulk of a solid body than the expansive feel of an aneurism.”

Soon after this, however, the nodulated character of the tumour became more marked, and three eminences, each about one inch in diameter, were especially prominent by the 10th of August, when also they began to assume a dusky red hue. One of these was on the right side of the tumour, another near the centre, and a third, the smallest but most elevated, lay close to the sternum. The pains now became more severe, and were accompanied by numbness in the course and distribution of the ulnar nerve; and, in short, all his symptoms were rapidly getting worse.

On the 11th, while getting up, he felt something give way in the tumour, fell back in his bed, and for some time had the appearance of one dying. He was with some difficulty restored by stimulants.

On the 12th, a portion of the central nodule assumed the appearance of a blister filled with dark serum.

On the 15th, the prominence to the right began also to point, and next day a small opening formed there, from which a drop or two of dark fluid escaped. This was followed, on the 17th, by a more copious though easily arrested hæmorrhage. For some days there was no recurrence of the bleeding, but new nodules and blisters formed close to the central one, and, by the 20th, a large superficial ulcer covered the centre and left of the tumour.

At this time Dr Macgregor wrote to me, and I suggested that the operation should be repeated. He did not, however, feel himself warranted in doing so alone, and I was unable to go to Glasgow.

The rest of the case is a story of repeated hæmorrhages. On the 22d, there was bleeding from the little orifice to the right, which is described as being occupied by a coagulum that advanced and retired with each pulse in the aneurism. The 24th witnessed yet

another from the same source, and, on the 25th, a stream of blood spouted from it to a distance of fully two yards. Two hæmorrhages from the central ulcer took place on the 28th, and the last was so copious that, after soaking through the bed, it formed a pool on the floor. From this the patient died.

The post-mortem examination was made by Dr Macgregor six hours after death. The large central ulcer measured three inches across, and in it were three orifices. One was patent, the two others were plugged by coagula. The orifice in the right of the aneurism admitted a large goose-quill and was also occupied by a clot. The tumour was sliced like a brain. In the centre was a firm mass having the appearance and consistence of liver, but with a circularly striated arrangement. This was surrounded by liquid blood, which filled the space between it and the wall of the tumour. The sac itself could contain a closed fist, and the central mass was about the size of a hen's egg. The aorta was largely dilated and lined by a perfect sheet of calcareous matter, which shone like porcelain and rang to the stroke of the knife. It communicated with the external sac by a smooth opening the size of a two-shilling piece situated close to the origin of the innominate artery. The second, third, and fourth ribs were eaten through, and the right edge of the sternum and lower border of the clavicle were in a state of carionecrosis. The heart was enlarged and the semi-lunar valves were calcareous.

In sending me the notes from which I have compiled the history of the case, Dr Macgregor says,—“The post-mortem examination clearly proved that a considerable quantity of blood had undergone coagulation by the galvanism; and had the orifice in the artery been not quite so large, and the galvanism been more frequently or longer applied, success might have been the result.”

It is evident that the patient's death was but little if at all delayed by the operation. The history seems to me to indicate the following as the course of events:—A coagulum, adherent to the wall, was formed in the lower part of the tumour by the first operation, and the aneurism thereafter extended upwards. This clot was increased in size by the second, and the pulsation was thereby notably diminished. Still, not being entirely occluded, the aneurism continued to grow in various directions, and ultimately, in consequence of this growth and on the occasion of a slight exertion, the clot became separated from the sac. The “giving way” sensation very probably marked the occurrence of this separation, which was followed by a speedy thinning of the aneurismal coverings. I have little doubt that even then, had I been able to operate a third time, death by hæmorrhage would have been obviated; but from personal causes I could not leave town so often as I could have wished.

Although there is nothing particularly novel in the circumstances of this case, it corroborates the conclusions to be drawn from the one I have recorded in my former paper. It is evident that the

action of galvanism when carefully controlled is not productive of danger to the patient. The care taken to prevent cauterization of the sac, by avoiding contact of the exposed portions of the needles with it, obviated in great measure that tendency to inflammation which had proved a source of danger in other hands. Moreover, the insulation, pretty well attained by the glass and gutta-percha,—perfectly so by the vulcanite coating of the needles,—prevented that sloughing at the points of entrance which has on more than one occasion given rise to unpleasant results by hæmorrhage and otherwise.

While, then, little danger to the patient is to be apprehended from the operation, this case seems to show the possibility of occluding the external portion of an aortic aneurism. Although it cannot be absolutely demonstrated that the central clot was produced by galvanic action, its nature and position, taken in connexion with the experiments made on blood external to the body, with other like cases, and especially with the one I shall presently relate, make it extremely probable that it was so produced. How much was due to direct galvanic action, how much to subsequent deposition, it is impossible to say, though doubtless the greater part was immediately coagulated. But being there, it follows as a matter of course that, if a clot of the size of a hen's egg could be produced by two operations of twenty minutes each, more frequent and longer continued operations will have a yet greater effect, even to the filling by coagulum of any size of sac. In this respect I speak only of the sac external to the thoracic wall, for the hope of curing an aortic aneurism by galvanism cannot be seriously entertained. Not to speak of the impossibility of placing electrodes in accurate position in the thorax, or of the probability that whatever might be formed would be at once carried away by the rush of blood, it is certain that any clot formed under such circumstances would become free on withdrawal of the needles and would pass on to plug up the aorta or one of its branches. Galvanism in aortic aneurism is to be regarded in the same light as tracheotomy in that disease, as a means of prolonging life in exceptional circumstances, to be used only when the obvious tendency to death is by the way which it is calculated to prevent.

But while we must in this and other directions set limits to the capabilities of electrolysis, we have also examples of its perfect applicability to certain forms of aneurismal disease; and I have great pleasure in relating a case of cirroid aneurism in which it afforded most complete relief.

About a year ago, James Gordon, a labourer, twenty-one years of age, consulted Dr Hardy of Leith, for an eczema of the scalp. In examining the head, Dr Hardy observed a cirroid aneurism, and recommended the man to go to the Royal Infirmary. He was there cured of the eczema; but it was thought injudicious to interfere with the tumour, and on leaving the hospital he put himself under my care.

The tumour was situated on the left side of the head, and reached from the vertex to the zygomatic arch. It resembled very closely in shape and size the half of a large Jersey pear. Its broad end lay upwards, and the enlarged temporal artery entered it below. The external carotid also was distended, and even the common carotid seemed large, and beat with unusual force. In front, the left anterior temporal artery curved round to enter the tumour; behind, the left occipital could be traced from it to the muscles of the neck; while the right temporal also contributed by means of its middle branch. The whole tumour pulsated strongly, and contained no clot. By firm pressure it could be so emptied of blood that the bone felt hard and firm, but it rose again at once on the hand being removed. A loud and prolonged bruit accompanied each pulse; and the constant sounding in the ear was the great cause of the patient's distress. By compression of the carotid or left temporal artery the pulsation was greatly diminished, and the tumour rendered very flaccid; but pressure even on all its distinguishable affluents did not prevent a slight pulsatory movement.

It was evidently a case in which other means would be so dangerous and uncertain that galvanism deserved a trial.

On the 20th of July, assisted by Drs Fraser, Hardy, and Joseph Bell, I operated for the first time. The needles, having one inch of exposed surface, were entered at the vertex and placed parallel to each other, about an inch apart. Four cells were used, and the action was continued for twenty minutes. Pressure was maintained up the affluents throughout the operation. The closure of the circle produced a smart shock, causing the patient to quiver; and another, not so severe, accompanied the opening. During the action a painful burning sensation was experienced; and in this, as in subsequent operations, Gordon stated that he distinctly heard the "blood boiling" in the tumour. When the current had been continued for about ten minutes, the aneurism began to swell; and soon afterwards the tympanitic note on percussion became audible. A slight flow of blood followed the withdrawal of the needles, but it was at once checked by lint and a bandage.

The same evening there was slight œdema all over the swelling. On its subsidence next day, there was felt in the centre of the tumour a hard nodule, divided into two parts by a tortuous pulsating passage.

At a second operation, on the 4th of August, the needles were introduced one on each side of the central nodule, and six cells were used. The shocks on closing and opening caused the patient to start violently, and tremble for about a minute; but the burning pain was not greater than with four cells, and was easily endurable. The action was stopped after twenty minutes, on account of an accident to one of the cells. The effects were precisely as already detailed. The hard core was increased in size, and the rest of the tumour continued to pulsate as before. From the negative needle

not having been deeply enough buried, a piece of skin not larger than a pea was cauterized and separated in a few days as a thin scale.

On the 8th of August one needle was placed in the middle pulsating passage, the other towards the back of the tumour, and farther additions were made to the consolidated mass. On this occasion the patient became a little sick from the pain, and the circle was opened after eighteen minutes' action, to relieve his uneasiness.

I was now for some time prevented from seeing the patient, but by the 28th of August no change had occurred; and on that day, with the help of Dr Andrew Inglis alone, I put the patient under chloroform, to avoid the shocks, which he greatly dreaded, and proceeded to repeat the operation. The initial shock, however, caused him to throw up his hand and draw out one of the needles; and as we found ourselves unable to control him, and at the same time manage the battery and the chloroform, I contented myself with binding up his head to stop the bleeding.

On the 31st, another failure occurred; for the patient had, contrary to orders, eaten largely before the operation; and after about five minutes' action it was found impossible to keep the needles in position, on account of his motions in vomiting.

On the 5th of September, however, a most successful repetition was made. The positive needle was introduced about an inch above the zygoma, and placed with its point directed upwards; the negative had its point directed downwards in the front of the main tumour. They overlapped about half an inch, and were more than that distance apart. A current from four cells was passed through them for twenty-five minutes. The immediate effects on the aneurism were much as before; but when I saw the patient in the evening, he stated that the bruit had entirely disappeared; and on applying the stethoscope I found that it was so. Two days afterwards, when the œdema had quite subsided, I made a careful examination. The neck of the tumour above the entrance point of the positive pole was consolidated; below that point it had collapsed. The temporal and carotid arteries had resumed their normal size. The centre of the tumour was entirely occupied by a hard mass, but between this and the surface was a fluid pulsating layer supplied by four tortuous and enlarged vessels, viz., the right temporal, the occipital, and two branches of the left temporal, which ran one before and the other behind the obliterated neck, and entered at opposite points half-way up the tumour.

On the 12th of September, I proceeded to obliterate this superficial layer, by introducing the negative needle pretty deeply behind, passing it even through the coagulum, while the positive was placed in the fluid portion slightly anterior to the middle line of the aneurism. After twenty minutes' action I observed a slight lividity

of the skin over the positive needle, and at once stopped the current. Unfortunately it was too late, for next day it became evident that the skin had been cauterized over a space about the size of a shilling. The whole mass was now, however, consolidated, except where the anterior and right temporal arteries entered, and neither portion was larger than a threepenny-piece. I obliterated the anterior a week afterwards, by passing under it a needle and compressing it for twenty-four hours by means of a piece of cork, secured by a figure-of-eight silk thread. The same process was not successful with the right temporal, and the patient would not allow me to repeat the attempt, as he had returned to his work, which he did not wish interrupted. The rest of the history is entirely favourable. The slough, much smaller than had been anticipated, was very dry and tough, and took a month to separate. But, six weeks after the last galvanic operation, the cicatrix was the only trace that remained of the tumour, with the exception of a slightly enlarged right temporal and a barely distinguishable occipital artery. The man has continued to work since that time, and there is no tendency to a development of the disease from these sources. If there were, a needle passed under or through these small vessels would serve effectually to obliterate them.

The very satisfactory termination of this case should, I think, be sufficient to establish electrolysis as a valuable therapeutic agent, well suited to the treatment of cirroid aneurism. The only real difficulty which attended the operations was to get a maximum of effect without endangering the skin. I had previously met with the same difficulty in applying electrolysis to a nævus in the eyelid of a child. Very small needles were then used, and the current was continued for a few minutes only. Only a small central induration was, in fact, produced; and, as some impatience was expressed, I resorted to subcutaneous ligature instead of trying a more efficient application of the battery. Till the last operation on Gordon's head, I succeeded in erring on the safe side; but, notwithstanding, nay even in consequence of the mistakes in that one instance, some facts may be elicited for guidance in future. The first operation affords, perhaps, the best data for estimating the coagulating power of electricity under given conditions. As I have already said, four cells of a Bunsen's battery were used; the period of action was twenty minutes; the active portion of each needle¹ was one inch in length, and their thickness No. 16 of the wire guage. A hard coagulum was formed, of which the breadth was an inch and a third; but a narrow uncoagulated passage remained rather nearer the negative than the positive electrode. Now this passage was, in all probability, due to a vessel lying just within the surface of the coagulum, which

¹ The needles which I used were made of steel, some gilt, others not so. The difference in action is unimportant; but the former want sharpness, the latter rust through use. I have sometimes had them gilded, and the points afterwards sharpened.

would thus be perfectly continuous behind it, and may in any case be very fairly estimated at one and a quarter inch in breadth and rather less in thickness. The length was one-fourth greater than that of the exposed steel, to which, of course, it will always correspond.

The intermediate operations afford no reliable data for such an estimate, on account of the relation which the needles bore to each other and to the already-formed clot; but the last is again of some importance. All other conditions being the same, the negative needle was placed perhaps not quite three quarters of an inch from the surface, the positive certainly not half an inch. The former brought the coagulum, in which it lay, up to the surface; the latter cauterized the skin.

From these facts it may be safely concluded—

1st, That both needles are efficient.

2d, That, under the circumstances named, they are together capable of producing more than one cubic inch of coagulum, the greater part of which is due to the positive pole.

It must not be forgotten that we had here to deal not with liquid blood only, but with blood through which was scattered a quantity of animal membrane in the shape of arterial tunics. Under the action of electricity the blood would coagulate on these, and by the acids and alkalis set free they would themselves be cauterized or inflamed. We had in them an adjuvant, which would increase the total amount of clot, and inflammation might be supposed the sole cause of efficiency at the negative electrode. Still, the action was immediate, not progressive, as it would have been had inflammation been the cause of coagulation; and for this and other reasons, to be afterwards detailed by Dr Fraser, I believe that even in liquid blood the negative pole would not be totally inoperative. Meanwhile it is practically proved to be useful in a cirroid aneurism, and to have materially aided in the cure of Gordon's disease.

In one respect, the presence of arterial walls gives rise to inconvenience; it produces a not inconsiderable amount of pain. In this respect the records of cases differ greatly. In most of them the pain has been described as of the most excruciating character; but, on the other hand, the first of the three subjects of aneurism on whom I operated suffered absolutely no pain, and with Lee it was comparatively trifling. In the cirroid aneurism the shock which accompanied the closure of the circle was bearable with four cells, though it caused the patient to start; but he was utterly unable to control himself when six cells were used. The opening of the circle was nearly as painful, and during the passage of the current a burning sensation was felt, which, though it was not unendurable, and did not palpably increase in intensity as the action continued, was yet undoubtedly severe. I am of opinion that the cause of this discrepancy lies mainly in the amount of solid tissue under the electric influence. In the earlier applications of galvano-puncture

there was either no insulation at all, or an insulation confessedly defective. In Mr A.'s case the walls did not suffer at all, in Lee's but slightly, while in Gordon's the needles passed through a considerable quantity of sensitive matter. Moreover, the smaller the aneurism operated on, supposing the insulation perfect, the greater probably will be the pain; for, in a small one, the free acids and alkalis will be much more likely to reach the aneurismal tunics, and the exposed points of the needles will be more apt to come in contact with them.

The pain, however, is of little moment, if the patient be under the influence of chloroform. The great object, and, I may add, difficulty in an ordinary aneurism, is to prevent that amount of irritation which is liable to excite a dangerous inflammation. On this ground, as on every other, there seems no cause for apprehension in a cirroid aneurism; and for that form of disease galvano-puncture may, I think, be regarded as the safest, simplest, and most certain method of treatment. Ligature of large arteries, like the carotid, is extremely dangerous, and has been singularly unsuccessful. Out of eighteen cases, seven died, and only two were permanently cured. The perchloride of iron, though it has been successfully injected, is also liable to failure, and has, moreover, certain well-known risks attending it. Extirpation, ligature, and incision have been tried, but hold out little inducement to repeat them. Galvanism, however, has been successful in the only two cases in which it has been used; and, though several operations were required in each, not the slightest accident happened in either.

PART II.

A number of experiments were undertaken for the purpose of determining the method by which galvanism produces its effects on aneurism. In the remarks and details which follow, it must not be supposed that we have examined the question in an exhaustive manner. Our investigation has, however, been sufficient to throw a considerable amount of light on the practical bearings of the subject, such as, the time required to obtain a satisfactory result, the value as a nucleus of the products of either pole, and the power of battery advisable, as well as the best methods of avoiding shock or pain, of protecting from cauterization the sac and superficial textures, and, generally, of obviating the sources of danger. Many of our results are merely confirmatory of observations already made by others, but which had been undertaken for purposes quite unconnected with the present subject.

Several statements of a most extraordinary description have been published on the effects of galvanism on albuminous fluids; and one writer—Dutrochet¹—even flattered himself that by the aid of

¹ Ann. des Sc. Nat., 1831.

galvanism he could not only cause coagulation, but also produce vibrating muscular fibres in solutions of albumen. One of the earliest really valuable contributions to the subject was by Dr Scudamore, in 1824.¹ He found that a galvanic current passed through blood formed at the negative pole a mottled scum with copious disengagement of gas, and, at the positive, a dense black coagulum which afterwards assumed the appearance of charcoal. In 1832, Müller² published an investigation in which he described many of the effects of galvanism on blood and on white of egg, and believed that the results were due to decomposition of their salts and to oxidation of the electrodes. Ancell,³ Baumgarten and Württemberg,⁴ Steinlein,⁵ and, most recently, Neumann,⁶ have since adhered to his conclusions. Steinlein, in addition, distinguished the effects of various electrodes, and asserted that with a weak current no change occurred in the albumen when the platinum poles were used, while electrodes of oxidizable metals caused a rapid coagulation at the positive. In this, Steinlein supported the opinion of Schuh,⁷ who, however, had differed from him in referring the curative results mainly to inflammatory changes.

Apjohn, Bellingham, and Ristelli,⁸ have ascribed the coagulating powers of galvanism to the free acid which appears at the positive pole when salts are present in the electrolyte.

The most contradictory statements occur on the effects of friction-electricity. Gerhard, Hufeland, Kielmeyer,⁹ and Richardson,¹⁰ are found asserting that electric currents retard the coagulation of blood, while Scudamore¹¹ and Schroeder van der Kolk,¹² with equal distinctness, maintain that it increases and hastens the formation of clots. For our purpose, these statements are unimportant. At an early stage of this investigation we satisfied ourselves that chemical decomposition was by far the most efficient, if not the only, cause of those actions on albumen which render galvanism a valuable means of treating aneurism. We accordingly restricted our inquiry to the effects of galvanism or chemical electricity, as it has been

¹ An Essay on the Blood, comprehending the chief circumstances which influence its coagulation, etc., p. 56, *et seq.*

² Elements of Physiology, translated by Baly, vol. i. p. 133; and Poggen-dorf's Annal., 1832.

³ Lectures on the Physiology and Pathology of the Blood. *Lancet*, 1839-40.

⁴ Medical Times and Gazette, 16th Dec. 1864, p. 620; and Wien. Zeitschrift, 1853.

⁵ Zeitschrift der k.k. Gesellschaft der Aerzte zu Wien, April, 1853.

⁶ Archiv für Anat. Phys. und Wissen. Medicin. Reichert und Du Bois Reymond. 1865.

⁷ Zeitschrift der Wien. Aertze, 1850.

⁸ Gazette Médicale, 1847.

⁹ Quoted by Dr J. Franz Simon. Animal Chemistry (Sydenham Society), vol. i. p. 116.

¹⁰ The Cause of the Coagulation of the Blood: Astley-Cooper Prize, 1858, p. 96.

¹¹ Op. cit., pp. 54-56.

¹² Quoted by Simon, op. cit., p. 117.

perfectly demonstrated that a direct ratio exists between the quantity of electricity passing through any given electrolyte¹ and the amount of resulting decomposition, and that the electricity developed by even powerful friction-machines is extremely small as compared with that which may be obtained from the weakest form of voltaic or galvanic battery.

EXP. I.—A solution of egg albumen, of sp. gr. 1055, and of slightly alkaline reaction, was placed in a conical glass, which it occupied to the depth of 1·5 inch. Two platinum needles, connected with a six-celled Bunsen's battery, were suspended perpendicularly in this solution, 0·75 inch apart, and dipping 0·75 inch into it. The circuit was closed by means of a key, and, immediately, bells of gas appeared on both electrodes, and increased rapidly in quantity till they formed a complete sheath round each, when many successively detached themselves and rose to the surface of the liquid. At the negative pole, the bubbles were all of minute size; but at the positive, many large bells were formed by the coalescence of smaller ones. In thirty seconds, test-paper exhibited a strong alkaline reaction at the negative and an acid at the positive electrode. In one minute, the positive pole had surrounding and adhering to it a thin sheath of opaque substance. This coagulum increased rapidly, and in five minutes a considerable layer surrounded the pole and extended from it in the shape of flakes and threads and opaque coverings of the larger oxygen bells. At the lowest portion of the electrode, it extended with much less rapidity than at and near the surface of the solution, so that it assumed the form of a pretty regular cone. By this time, the negative needle was completely enveloped in a mass of froth, which also possessed a conical configuration, though there was a marked extension of the frothy growth towards the positive electrode. In ten minutes, the whole surface of the liquid was covered with a mass of froth, which had a prominence surrounding each needle. The circuit was opened in twenty minutes. It was found that a dense opaque substance of conical form, about 1 inch in depth and 0·5 inch in greatest diameter, entangling a multitude of bells and having an acid reaction, had formed at the positive electrode. At the negative needle, a perfectly-defined irregularly-conical substance of alkaline reaction was found, rather more bulky than the positive coagulum, having the appearance of a clear and colourless jelly, and enclosing a mass of consistent froth. A small quantity of unchanged white of egg occupied the remainder of the glass.

The two results were placed in contact with distilled water. The clear jelly which was formed at the negative electrode gradually swelled up, but remained undissolved for three days. The opaque substance derived from the positive electrode was apparently unaffected by water; a portion retained its characters until it

¹ The compound decomposed by electrolysis (ἤλεκτρον and λύειν): these terms were introduced by Faraday, and are now generally employed.

commenced to decompose, and another portion was found to be soluble in heated caustic potash, and formed a deep brown solution.

EXP. II.—A trough was made with gutta-percha, across the middle of which a piece of De la Rue's parchment was stretched so as to divide it into two cells, each of which had a diameter of 1 inch. All the other conditions being the same as in the first experiment, an electrode was placed in each cell. On closing the galvanic circuit, the same phenomena also occurred. In eight minutes, the coagula had become irregular by their lateral and anterior extension being greater than the posterior; and in the positive cell, lines of opacity were seen extending towards the parchment partition, and adhering to it. In thirty minutes, there was almost no unchanged albumen in either cell. The positive contained an irregular opaque coagulum, with a number of partially detached threads and patches. A somewhat dense sheet enclosed this coagulum, and adhered slightly to the surface of the partition, while all its contents were strongly acid. In the negative cell a quantity of consistent froth, about 0.25 inch in diameter, surrounded the electrode, beyond which there was a clear area limited by a thin opaque membrane, which adhered slightly where it was in contact with the partition. At first sight, this clear area appeared to consist of unchanged albumen; but, on removing the contents of the cell, it was found to be in reality a very firm and clear jelly, of a conical form, and with the diameter of 1 inch at the surface and 0.25 inch at its lowest point or apex. There was a very small quantity of liquid albumen in this cell, and it, as well as the frothy substance and the jelly, gave a powerfully alkaline reaction to test paper. The other characters of these results agreed with those of the first experiment.

EXP. III.—Serum obtained from the blood of a sheep was treated in the same way, with exactly the same results.

EXP. IV.—The fluid removed from a hydrocele was also acted on by galvanism, and yielded the same forms of modified albumen at each electrode.

EXP. V.—No special results were obtained when defibrinated blood was similarly treated, except a slight modification of the clots, which was due to the presence of colouring matters. This was principally a blackening of the coagulum at the positive electrode, by the action on blood pigment of the acid radicles which are there set free.

EXP. VI.—To obtain pure albumen, white of egg was dialyzed according to the process of Graham. The result was evaporated, at a very low temperature, to the sp. gr. of 1056, and treated with galvanism in the same way as in the preceding experiments. We found that changes were produced at both electrodes, which only differed from those in white of egg by the smaller quantity of the results. This was very unexpected, as the absence of inorganic matters in solutions of pure albumen should have modified the effects of galvanism to an important extent. A portion of the solution was therefore dried, and, on incineration, a small quantity of inorganic matter was obtained, proving that we had not succeeded

in completely eliminating the salts. Until we obtain an absolutely pure albumen, we can fortunately make use of some experiments by Smee,¹ with an albumen which he believed to be perfectly free from inorganic impurities.

Our experiments were modified by substituting albuminous fluids of different specific gravities, and by approximating and lengthening the distances between the electrodes. As might be supposed, a dilute solution yielded a mere flocculence, while one of much higher specific gravity than blood rapidly yielded the characteristic results; but, beyond a certain point, the growth of the clots was impeded, in the latter, by the interruption to the galvanic current which was produced by the dense masses formed.

EXP. VII.—Complete anæsthesia was induced by chloroform inhalation in a small mongrel dog, and the left femoral artery was exposed. Two German silver needles, bent at an angle of 60, and insulated beyond the bend with sealing-wax, were connected with a six-celled Bunsen's battery, the circuit of which was closed and opened by a key. They were then inserted into the exposed artery a short distance beyond their angles, with their points towards each other and one inch apart,—the needle which was next the heart being positive to the distal one. On closing the circle a slight tremor occurred. In twelve minutes, the pulsation between the two needles, and for a short distance below them, had ceased; and, on opening the circuit, in fourteen minutes, a faint tremor was again observed. The vessel was ligatured a short distance above and below the insertions of the needles, and the intermediate portion was dissected out and removed. The artery was carefully opened with a pair of scissors, and its whole calibre was occupied by a dark clot containing a small quantity of froth, and this clot extended a short way beyond the points of insertion of the needles. Opposite to and slightly below the point at which the positive needle had entered, a small surface was observed in the interior of the vessel, which had apparently been cauterized by the needle.

EXP. VIII.—A small terrier dog was put under the influence of chloroform, and its abdominal aorta was exposed. The same battery was used as in the previous experiments, but larger needles were employed, and they were placed about 0.75 inch apart, the positive being proximal to, and the negative distal from, the heart. A slight shock occurred when the circuit was closed. In four minutes the pulsations between the electrodes were barely perceptible; and, in twelve minutes, when the circuit was opened, they had completely disappeared, remaining distinct above and down to the proximal needle; while, below the distal one, the artery was slightly collapsed, and appeared empty. It was found that its whole calibre was occupied by a dark clot, which extended from the point of insertion of the higher electrode to a considerable distance beyond the lower. The artery immediately above the electrodes was empty, as the animal had been bled to death.

¹ Proceedings of the Royal Society of London, vol. xii., 1862-63.

EXP. IX.—The left femoral artery was exposed in a small mongrel dog, which had been rendered unconscious by the inhalation of chloroform. Similar electrodes and the same battery were used as in the other experiments, and the needles were introduced 1 inch from each other at their points of insertion; but, in this experiment, the proximal needle formed the negative, and the distal the positive electrode. A slight tremor occurred on closing the circle. In five minutes, the pulsation between the needles had distinctly diminished; in six minutes, it could be distinguished immediately below the proximal needle only; and, in fifteen minutes, it had completely ceased within the galvanic circle. The application was stopped in sixteen minutes, and the wound sewed up. The dog was killed in seventy hours. On opening the artery, a firm, slightly adherent clot was found, which apparently filled the vessel; it was 1 inch in length, and consisted of a small colourless portion at the proximal end (negative needle), and of a larger portion of a reddish brown colour.

EXP. X.—The right carotid artery and the right internal jugular vein were exposed in a dog. The same battery and similar needles were employed. The positive electrode was introduced into the vein, and the negative into the artery, at a distance of an inch from each other, and in such a manner that the two points were opposite, and the bent portions of the electrodes in the direction of the blood-streams. In eight minutes after the closure of the circle, no pulsation could be perceived immediately above the entrance of the negative needle into the artery, and a black clot could be distinguished in the vein. For about 0·75 inch below the electrode in the artery no pulsation occurred after ten minutes, while it was very distinct nearer the heart. Bells of gas could be discovered both in artery and vein, in the neighbourhood of the needles. In seventeen minutes, the circle was opened. It was observed that in the vein there was a black areola of cauterization surrounding the penetrating needle, but no hæmorrhage occurred when it was withdrawn. A little force was necessary in removing the negative needle from the artery. The dog was immediately killed. A small thin clot was present in the vein about 0·5 inch in length, and in the artery a large one with gas bubbles extended about 2 inches below the perforated point.

These experiments on bloodvessels have given perfect evidence of the power of electrolysis to occlude them, and have also shown that this efficiency does not pertain to one electrode alone, but is shared in by both. Their bearing on the treatment of cirroid aneurisms is very evident.

Some attempts were now made to discover the exact effects on blood contained in aneurismal sacs, or, at least, on such large quantities of living and moving blood as would enable us to ascertain whether appearances were produced similar to those which occur in albuminous fluids and in defibrinated blood. With this view, efforts were made to produce aneurisms in dogs by incisions

into arteries. Had we succeeded we should have been in a position to distinguish, without hesitation or dubiety, the effects of the galvanism from those changes which spontaneously occur in living blood. Our success was, however, limited to the production of short-lived pulsating hæmatomata, as we had the misfortune to operate on dogs which, for our purposes, possessed most unfortunate powers of curative vitality. We eventually succeeded in designing a form of apparatus which possessed many of the required conditions. Two glass hemispheres were constructed which were furnished with adapting screws to admit of their junction, and of the consequent formation of a globe capable of containing five ounces of fluid, and having two tubes entering at opposite points. By attaching india-rubber tubing to these, the apparatus could be connected with a bloodvessel. There were other two perforations in this globe to admit the electrodes, which might, by a simple mechanical arrangement, be readily introduced into or withdrawn from the interior of the globe, and an opening at the top permitted the escape of contained air as the blood entered.

EXP. XI.—The left femoral artery of a large retriever mastiff was exposed and divided, and into each portion a nozzle, connected with the india-rubber tubing of the glass aneurism, was inserted. The entrance of blood was easily controlled by attached clips, and a temperature a little above 85° Fahr. was maintained by placing the globe in a hollow water-bath. On opening the clips, the blood flowed freely into the aneurism, and, as soon as the contained air had been expelled, the galvanic circle was closed by means of a key. Gas bells, in a short time, rose to the upper part of the aneurism, and surrounded the electrodes which were there situated; and, through the glass wall, we could readily observe frothy masses slowly growing and accumulating round each pole, from which now and then a very small cluster of bells detached itself and was carried off,—first, in those irregular transits which marked the course of the blood-stream in our aneurism, and then suddenly down the exit tube to enter the distal portion of the divided bloodvessel. We had already found that in this apparatus the blood might be expected to coagulate spontaneously, in a very few minutes. After eight minutes, pulsation was yet perceptible in the exit tube, when the galvanic circuit was opened, and the entrance of blood stopped by closing the india-rubber tubing. The electrodes were withdrawn, and on unscrewing the hemispheres a little fluid blood was found, and a large coagulum, possessing nearly the exact configuration of the interior of the glass aneurism. At the surface two round holes were seen, which had been occupied by the electrodes. Immediately surrounding the orifice of the positive pole was a black ring, and beyond this a firm clot, with entangled gas bubbles. The position of the negative electrode was surrounded by a quantity of froth intermingled with clotted blood. Both were perfectly distinguishable from the normally coagulated blood, and both possessed greater consistence and tenacity than it. A section

was made through the globular clot at the points where the electrodes had entered it. It was found that the electrolytic clots extended an inch into the mass, in a conical form. The negative had a diameter of 0.75 inch at the surface or base, and had a markedly alkaline reaction; the positive was 0.5 of an inch at its base, and was strongly acid. A few black lines were also exposed in this section, which were apparently connected with the positive electrode, and proceeded from it in wavy and fantastic courses, to be lost in the general blood mass. A microscopic examination of the blood revealed many of those curious marginal modifications of the corpuscles which Rollet¹ and Neumann² have fully described, and to which the attention of this Society has been already directed by Dr Wright.

In attempting to solve the question how galvanism produces a blood clot it is necessary to ascertain whether the chemical effects of electrolysis are sufficient to account for the changes which occur. Our data all point to the conclusion that such is the case. There is no evidence to support the view that the mere passage of electricity or of galvanism through soluble fibrin converts it into a coagulum. In the first portion of this paper, it has been shown that when the electrodes are inserted at a short distance from each other in an aneurism, two separate areas of hardness and condensation result, with an intervening unchanged space. Through this space the galvanic current must have passed, and yet the fibrin in it has remained uncoagulated. The same was observed with our glass aneurism. Did any power of coagulating fibrin or albumen exist apart from chemical reaction, it would be reasonable to expect such an effect after the passage of an electric current; but the evidence tends rather to show, from experiment and accident, that the reverse is the case, and that fibrinous coagulation is retarded by friction-electricity.

Albuminous fluids, absolutely free of inorganic impurities, are acted on, but the results may be produced by chemistry alone. Smee has proved that the threads and patches which appear at the positive electrode, after the protracted passage of a galvanic current through a solution of pure albumen (and which he attempts to prove are really fibrin), may be exactly imitated by the direct action of oxygen: the electrolytic decomposition of water being, therefore, sufficient to account for their presence. The principal salts found in white of egg are chlorides, phosphates and sulphates of potassium, sodium, calcium, magnesium, and iron. A galvanic current causes the decomposition of these, and the appearance of the acid radicles at the positive, and of the basic radicles at the negative electrode. In this way, selecting the predominant of these substances, chlorine, acid-albumen, and oxygen will appear at one pole, and free sodium and potassium, with nascent hydrogen, at the other. Sodium and

¹ Veränderungen an den rothen B. Körperchen, in den Sitzungsberichten der Wiener Akad. d. Wiss. V. 46, 47, 50:

² Op. cit.

potassium will, however, become immediately converted into soda and potash by their action on water, and these combined, on the one side, with chlorine and oxygen at the other, are sufficient to account for the changes which immediately occur. Soda and potash, in very concentrated solutions, convert white of egg into a clear and firm jelly; chlorine and oxygen cause it to assume an opaque and flocculent form. A gentle stream of hydrogen with the basic, and of oxygen with the acid radicles, will produce a clear jelly with entangled froth, and an opaque substance with mingled gas bubbles, in no way distinguishable from the results which occur at the negative and positive electrodes.

The changes produced in blood may be accounted for in a similar manner. In man, the principal inorganic constituents of this fluid are chlorine, sulphuric and phosphoric acids, sodium, potassium, iron, calcium, and magnesium. Electrolysis transfers the acids to the positive electrode along with oxygen, and the bases to the negative along with hydrogen. The suspended albumen is attacked at both poles, and effects follow which experiment can readily demonstrate to be the consequences of the chemical action of acid radicles at the positive, and of basic radicles at the negative electrode. The black coloration of a portion of the positive clot is probably due to the action of nascent oxygen on hæmatin. The froth formed at both poles, and its different appearances and proportion, are obviously the effects of the natural and increased viscosity of the blood, and of the different proportional rapidity with which oxygen and hydrogen are formed in the electrolysis of water. That the gas should be entangled by the blood is of considerable importance, as the size of the clots is thereby increased and their curative value proportionally enhanced. Schuh,¹ Baumgarten and Würtenburg,² Althaus,³ and Garratt,⁴ doubt the efficiency of the negative pole, and even propose modifications to dispense with its insertion into the aneurismal sac. We will not dwell on the methods by which it is proposed to accomplish this, as our results suffice to show that the negative electrode is at least as valuable as the positive. The mass of frothy substance is certainly not so dense as the clot at the positive pole, but it is of sufficient consistence to remain undissolved for several days, and it has the great advantage of being larger.

A certain quantity of gas passes through the blood without being entangled or absorbed, and either accumulates at the highest portion of the sac, or is removed by the blood-current. In the latter case,

¹ Wien. Zeitschrift, 1850.

² Op. cit.

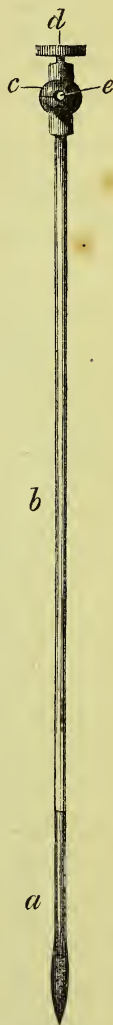
³ Med. Times and Gazette, 1862; and, On the Value of Galvanism in the Treatment of Paralysis, etc., 1866, p. 16. Dr Althaus has apparently modified his views on this point, since the publication of the two papers referred to. In his recent communication "on the Electrolytic Treatment of Tumours and other Surgical Diseases" (British Medical Journal, 11th and 16th May 1867), the value of the positive needle is denied, and the introduction of the negative alone is strongly recommended, on the "principle, that it is to the use of this pole that we have to look for the cure of aneurism."

⁴ Electro-Physiology and Electro-Therapeutics, etc. By Alfred C. Garratt M.D. Boston: 1860. -P. 651.

there is not the slightest reason to apprehend danger from its entrance into the circulation, as it is generated so slowly, and in such extremely small bubbles, that the total quantity produced during an ordinary application is quite unimportant as a cause of risk to life. If it should be found that this gas produces local distention of the sac or other inconvenience, its appearance might be prevented by covering the negative electrode with a layer of metallic peroxide—possibly with lead peroxide—the oxygen of which would be at once attacked by the nascent hydrogen, and water, in place of gas, would be produced.

Steel is certainly the best form of electrode to employ, from the ease with which it can be introduced. If it be not gilded, the positive pole will be rapidly corroded; but when the wire is about 0.075 inch in diameter, it is not acted on to such an extent as to have its efficiency seriously impaired. Besides, when blood is the electrolyte, its corrosion results in the formation of ferrous chloride, and, probably, of ferrous sulphate,—salts which coagulate albumen, and thereby increase the wished-for result.

It is of importance to protect the textures perforated by the needles from the electromotive force, as, otherwise, pain and inflammation of the aneurismal coats, with probably dangerous hæmorrhage, would be caused. This has been a great obstacle to the adoption of galvanism in the treatment of aneurism, and we made many experiments with various insulating materials to overcome this objection. Glass and sealing wax, varnish of various kinds, caoutchouc and shellac, were successively subjected to trial without giving satisfaction. The more brittle of these substances splintered, and the others were peeled off by the resistance of the perforated textures. At Dr Wright's suggestion, and with the aid of Dr Smith's valuable practical knowledge, this difficulty has been overcome, and we can now recommend for the purpose a coating of vulcanite. This can readily be placed round the needle, and from its smooth, extremely hard surface, and its property of nearly complete insulation, it may be introduced into the sac with great facility, and without producing the slightest cauterization.¹



¹ The woodcut represents the needle now recommended, and is of the exact size. Its thickness is 0.07 in., or No. 16 of wire-gauge. The non-insulated steel portion, *a*, is about $1\frac{1}{8}$ in. in length; *b* is the insulated portion, of about $3\frac{2}{8}$ in. in length, and previous to the application of the vulcanite (or ebonite) this portion of the needle is thinned to allow the layer of vulcanite to be flush with *a*; *c* is the brass head, having a screw, *d*, to fix the wire from the battery or key, which is inserted into the hole, *e*.

The purpose of this portion of the paper has been served if it has succeeded in showing what effects galvanism produces in blood, and how these are caused. The value of electrolysis seems to depend on its bringing in contact with a coagulable fluid a number of substances which produce coagulation, and which are generated so slowly and gradually, that the areas of their action may be strictly limited. It, at the same time, supplies, at the points of action, rods of support, to which the changed albuminous particles naturally attach themselves, and on which the blood-clots grow until they are sufficiently matured to adhere to the internal surface of the aneurismal sac, or at least to occupy a considerable portion of the cavity.



