ON THE REPAIR
OF
ARTERIES AND VEINS AFTER INJURY.

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FROM numerous experiments made by Dr. Jones¹ he came to the conclusion that when an artery was divided, three coagula were formed in the process of repair—one of blood externally, one of lymph just within the extremity of the canal, and one of blood within its cavity. "I have called that of lymph a coagulum," he observes, "because it may be considered a distinct substance—effused in such a quantity as to form a mass of a determinate figure." When a ligature is applied to an artery in the usual way the wounded internal surface of the canal, Dr. Jones says,² being kept in close contact by the ligature, adheres. "It seems to be entirely owing to the effusion of lymph that this union is effected."

¹ Jones on 'Hemorrhage,' p. 63.

² Ibid., p. 160.

Hunter in the same way believed that the lining membrane of the blood-vessels is subject to inflammation like other points, and that inflammation may terminate there as elsewhere in adhesion and suppuration. He says, "In cases where I have had the opportunity of inspecting veins after death, I have found the inflammation in the adhesive state; in some places the sides of the vein were adhering, and in others the inner surface of the veins was furred over with coagulable lymph."¹ From the account given of the first case in which Hunter tied the femoral artery for popliteal aneurism, in the 'London Medical Journal' for 1786, it is evident that his object was to procure adhesion of the opposed sides of the vessel. For this purpose he employed four ligatures, as appears from Sir E. Home's account of the operation (p. 295). Having, he says, disengaged the artery from its lateral connections with the knife, a double ligature was passed behind it by means of an eyed probe, and the artery tied by both portions of the ligature, but so lightly as only to compress its sides together. A similar application of ligature was made a little lower down. The reason for passing four ligatures was to compress such a length of artery as might make up for the want of tightness. On the ninth day after the operation there was considerable discharge of blood from the part where the ligatures passed out, and a tourniquet was applied. On the 8th of March, the operation having taken place in the previous December, the wound broke out again. The patient was ultimately dismissed as cured on the 8th of July following. It is evident from this description that Hunter expected adhesion of the opposed sides of the artery to take place, and as evident that such adhesion did not occur. What Hunter meant by adhesion he himself tells us: "In adhesive inflammation the vessels, being enlarged, begin to separate some portion of coagulating lymph with some serum, and also red globules, and throw it out on the internal surface, probably through the exhaling vessels, or perhaps open new ones, and cover

¹ 'Transactions of the Society for the Improvement of Medical and Chirurgical Knowledge,' vol. i, p. 23.

the sides of those cells which easily unite with the opposite, with which they are in contact, forming the first progress of adhesions.”¹

As lately as 1864 Sir James Simpson has expressed the opinion in his work on Acupressure that mere apposition is sufficient to close the largest arteries laid open in surgical operations.² And Mr. Lawson Tate, who appears to have adopted Sir James Simpson's principles and practice, states that if the coats of an artery are kept together for a few days they will unite.³ Now, all these authors seem to agree in the idea that the lining membrane of blood-vessels will secrete lymph in the same way as a serous membrane will do when it is inflamed. That such is not the case with regard to the lining membranes of veins Mr. Lee endeavoured to show in an essay published in vol. xxxv of the ‘Transactions’ of this Society for the year 1852.

It is the principal object of the present paper to demonstrate the nature of the process which results in the repair of an artery or a vein after it has been wounded. That it does not consist essentially in the effusion of lymph from the lining membrane of the vessel may be demonstrated. Virchow has given the particulars of thirteen experiments in which he irritated the lining membrane of arteries by various means. In none of these was there any plastic exudation from the surface of the lining membrane.

EXPERIMENT I.—A horse having been placed at our disposal by Mr. Dollar, veterinary surgeon, of Bond Street, the carotid artery was opened and the hæmorrhage suppressed as well as could be managed by compression and bandage. The animal was killed at the expiration of seventy-two hours. The wound in the artery, as shown by the accompanying preparation, is contracted and puckered, but there is not the least sign of any effusion of lymph on its lining membrane.

¹ Works by Palmer, vol. iii, p. 349.

² On ‘Acupressure,’ p. 535.

³ Braithwaite, ‘Retrospect of Medicine,’ vol. liv, p. 315.

EXPERIMENT II.—A donkey having been provided by Mr. Field, veterinary surgeon, an acupressure needle was left in contact with the main artery above the knee for three whole days. The animal was then killed. The artery, as shown by the accompanying specimen,¹ was red, and its coats apparently injected; but there was no trace of any effused lymph upon its lining membrane.

A patient in St. George's Hospital had the femoral artery tied for an aneurismal tumour. The patient died at the expiration of thirteen days, secondary hæmorrhage having recurred several times before the patient's death. The artery was tied with a silver wire which had very nearly eaten its way through the lining membrane of the distal portion of the artery. The interior of the vessel at this point is represented in the accompanying drawing by Dr. Westmacott (see Plate VII). The indented outline of the lining membrane can be distinctly traced, and may be seen to be quite free from any plastic effusion upon its surface. The tube is here partially closed by a decolorised coagulum, which has the slightest possible adhesion to the lining membrane of the artery; small portions of the same material adhere not very closely to the lining membrane near its termination.

Again, in Pirrie's work on 'Acupressure,' a case is related in which after an amputation of the thigh bleeding was commanded by acupressure needles under, and loops of wire over the vessels (Case V). The patient died thirty-six hours afterwards. The superficial femoral artery and vein were both included in the loop, and before the vessels were opened it could be distinctly seen that the artery contained a coagulum extending upwards from the needle for an inch and three quarters, and that the vein was empty to nearly the same extent. The artery and vein were both free from any trace of inflammation, and their coats were perfectly entire and unimpaired where they had been em-

¹ The specimens referred to are now in the Museum of St George's Hospital.

braced by the needle and loop. The obliterating coagulum in the artery was composed of three pieces adherent to each other and very slightly to the interior of the artery. (pp. 72, 73.)

That the process by means of which an artery or a vein when injured is repaired depends, as a rule, upon a different process to that which has hitherto been understood by *adhesive inflammation*, appears from the following observations :

An incision about an eighth of an inch in length was made by Mr. Lee through all the coats of the carotid artery of a horse, on October 29th, 1866 (fig. 1). The artery of the leg was also opened in two places close together, as shown in fig. 2. On November 1st, three full days after the operation, the animal was killed, and the vessels were carefully removed and examined. Upon slitting up the vessel with scissors a clot was discovered which extended from the opening for two inches in one direction and about one inch in the other. This dark red clot could be traced into the almost colourless material which plugged up the opening which had been made in the vessel as represented in fig. 1, but in no part whatever was the clot adherent to the lining membrane. A large quantity of blood had been effused into the areolar tissue forming the external coat of the artery, and had distended its meshes enormously, forming a firm mass more than half an inch in thickness, extending around the vessel for about two thirds of its circumference, as shown in the figure. The coagulum occupying the wound in close contact with the divided elastic coat of the artery was almost colourless, but in thin sections a few red blood-corpuscles could be detected here and here. Pretty equally distributed through it and at very short intervals were bodies having all the appearance of ordinary white blood-corpuscles. This colourless fibrin-like substance, rich in white blood-corpuscles, adhered to the divided arterial coats with tolerable firmness, and it is even possible that by its contraction it may have drawn towards each other the lips of the wound. In order to examine this rapidly-formed

tissue minutely, in the hope of ascertaining precisely its nature and origin and the mode of its formation, that small portion of the artery where the opening had been made was removed and, after having been transferred to carmine fluid,¹ was hardened in glycerine containing a very little acetic acid. When in a proper state, thin sections were made so as to include the arterial coats and adventitious tissue adhering to the cut surfaces. These sections were made in a direction at right angles to the longitudinal cut, fig. 4. The fibres of the circular fibrous coat encircling the artery are therefore seen lengthwise (*b*, *c*), while the longitudinal fibres forming the innermost portion of the arterial tunic are cut across transversely or obliquely (*a*). A thin section is represented in fig. 4 under a magnifying power of twenty-nine diameters, and in fig. 5, the portion marked *e* in fig. 4 is represented magnified 700 diameters.

One of the openings in the small artery of the leg, fig. 2, with its plug projecting for about the twentieth of an inch above the inner surface, is represented about the natural size, in section, in fig. 3; and in fig. 6 a section of a part of the same is seen under a power of 40 diameters. Figure 7 shows the structure of the laminated adventitious tissue represented in fig. 6, and fig. 8 some of the amorphous matter which was continuous with this and is evidently of the same nature, magnified 700 diameters.

It is a point of the greatest interest to determine the nature of the transparent tissue shown in figs 4, 5, 6, which occupies the opening made in an artery three days after injury, for this is the material by which the wound is temporarily repaired. In it the changes which result in the complete healing of the artery, and thus bring about permanent repair, take place. After careful examination of the texture itself and consideration of various facts previously ascertained in other inquiries,—upon the formation of fibrin in the blood, the development of tissue, and the formation of lymph upon serous membranes in inflammation,—we have

¹ For the composition of the carmine fluid, see 'The Microscope in its Application to Practical Medicine,' 3rd edition, 1867, p. 53.

Fig. 1.

Carotid artery of a horse, three days after operation. The opening is seen a little below the middle of the vessel, and passing from this is a clot which extends in both directions. Blood is extravasated in considerable quantity in the areolar coat of the vessel. Natural size.

Fig. 2.

Artery, leg of a horse, in which two punctures had been made, three days after the operation. The wound is already closed, and the fibrinous matter projects above the internal surface, as shown in section in Fig. 3. Natural size.

Fig. 3.

Section through artery, about middle of one of the openings, *a*, Fig. 2. Showing fibrine projecting above the level of the lining membrane of the artery. Natural size.

Fig. 4.

Vertical section through carotid artery at the seat of injury, showing one of the cut edges and the fibrinous material occupying the wound. *a*, innermost longitudinal fibres cut across; *b*, inner portion of circular fibrous coat of the artery; *c*, outer and coarser portion of the same; *d*, areolar coat. On the right, this is seen to be infiltrated with blood which passes into the colourless fibrinous material occupying the wound. $\times 29$.

arrived at the conclusion that this adventitious tissue occupying the wound is closely allied to, though probably not identical with, ordinary fibrin and is deposited from the blood, or rather is formed through the agency of the living germinal matter of the blood—the so-called white blood-corpuscles and corpuscles which have been detached from these.¹ Although there is a difference in the microscopical characters of ordinary fibrin deposited from the blood, and undoubted lymph formed upon the surface of a recent wound or upon a serous membrane in inflammation, we think this difference may be due to the different conditions under which the deposition of the insoluble material occurs. At any rate we have seen fibrin undoubtedly deposited from blood which exhibited no fibrous or “fibroid” appearance whatever—fibrin which exhibited delicate lines or striæ like lymph—and fibrin which could scarcely be distinguished from certain specimens of true fibrous tissue in process of development. And on the other hand we have seen specimens of unquestionable lymph recently formed upon the surface of the peritoneum which could not, we think, have been distinguished by its microscopical characters or its behaviour with acetic acid or potash from true fibrin.

Many facts we have observed lead us to the conclusion that the formation of what is called fibrin, lymph, and fibrous or connective tissue, is due to the conditions present and the rate at which the changes proceed, rather than to a difference in the properties or powers of the living matter which produces these substances. And we believe that the so-called colourless corpuscles of the blood, lymph, and chyle, and the corpuscles resulting from their division and subdivision may give rise to fibrin, to lymph, or to fibrous tissue. In the formation of lymph the small portions of living germinal matter known as white corpuscles or bodies derived from these which have escaped from the blood through the slight fissures in the walls of the over-stretched capillary vessels, are the active agents. In all

¹ “On the Germinal Matter of the Blood; with Remarks upon the Formation of Fibrin,” by Lionel S. Beale, ‘Trans. Mic. Society,’ Dec., 1863.

organizable exudations such masses of living germinal matter exist, and to these must be attributed the production of the material giving to the exudation its peculiar characters. If the substance be poured out upon the surface of a serous membrane, the germinal matter in it will live and grow, and continue to form a kind of fibrous tissue probably in consequence of being very close to the blood-vessels and receiving a supply of nutrient material. If on the other hand the fluid holding in suspension masses of germinal matter be poured out upon the surface of a mucous membrane, reaching it by passing first into some of the numerous glands or follicles opening upon the surface, the thick layer of epithelium which separates it from the blood-vessels will interfere with the free supply of nutrient pabulum. The germinal matter will die, and the mass can never become organized. In this case, although its origin and nature are the same, it is denominated an *unorganizable exudation* to distinguish it from the former, which is called *organizable*. Whether it dies and is thrown off (unorganizable), or lives and becomes an integral part of the body (organizable), depends upon its position and its relation to the blood, not upon any peculiarities in the exudation itself. We cannot admit that an inflammatory exudation consists merely of a fluid holding *in solution soluble matters* only. Small particles of germinal matter are invariably suspended in it, and although hitherto overlooked, these constitute the only active matter in the exudation.

Moreover, our observations upon the changes taking place in the blood which has extravasated into the areolar tissue in the external coat of the vessels seem to show that in the disintegration and removal of its lifeless elements, the white blood-corpuscles increase and multiply, and are in all probability actively concerned.

In fig. 11 some of the fat-cells in the areolar coat of a vein, with multitudes of little granular cells in the intervals, are represented. The preparation from which this drawing was taken was obtained from the outer part of the vein three days after it had been opened by Mr. Lee. Already the colouring matter of the extravasated blood

Fig. 5.
Edge of wound marked *c* in Fig. 4, magnified 700 diameters. The fibrinous matter extends over the inner surface of the artery, and in various situations white blood corpuscles are seen embedded in it. The masses of germinal matter (nuclei) of the inner part of the arterial tunic are well seen. They are little larger, close to the seat of injury, than in other parts of the vessel.

Fig. 6.
Section through one of the points of the artery of the leg, three days after operation, showing laminated arrangement of fibrinous material which occupied the wound and projected above the internal surface of the artery. See also Fig. 5. *a*, inner coat of artery; *b*, fibrinous material occupying the wound. $\times 10$.

Fig. 9.
Fat cells and areolar tissue from external coat of vein, three days after operation. Multitudes of bodies like white blood corpuscles, and probably direct descendants from them, are seen in the intervals between the fat cells, which in some instances were dyed with the altered and dissolved colouring matter of the blood, the greater part of which had however been removed. $\times 215$.

Fig. 7.
Laminated fibrinous material, from Fig. 6, showing masses of germinal matter (white blood corpuscles), now elongated, and fibrin-like substance, or formed material. $\times 70$.

Fig. 8.
Fibrinous matter not exhibiting laminae, showing germinal matter (white blood corpuscles), unaltered and fibrin-like substance formed by them. Fig. 6, $\times 500$.

Fig. 10.
Vein showing old cicatrix, probably resulting from bleeding.

Fig. 11.
Vein with opening, three days after operation.

has in great part disappeared, and the fatty matter of the fat-cells is in many cases tinged by it of a deep-brown colour. The little bodies, like white blood-corpuscles so very numerous, were evidently multiplying rapidly when the specimen was removed from the body of the animal. Here and there the remains of red blood-corpuscles could be discerned, pale and indistinct. That the corpuscles figured in the drawing consisted of living germinal matter, and were not altered red blood-corpuscles, was evident. For, first, they were readily coloured by carmine fluid; secondly, they varied much in size and were evidently multiplying; and lastly, they were spherical, exhibiting nuclei in their interior, and had that delicately granular appearance so characteristic of the white blood-corpuscle, pus-corpuscle, and other bodies composed of living germinal matter. It seems to us most improbable that these masses of germinal matter had been derived from the connective tissue corpuscles; for, first, the latter were not found to be larger than in the normal state or to exhibit any appearance of proliferation, nor were the bodies in question more numerous near the connective tissue corpuscles than in other situations. Secondly, they were so very numerous that it appears to us most improbable that they could have resulted from proliferation of the connective tissue corpuscles in the time. On the other hand, their general characters, their number, and the mode of their distribution, are such as we should expect to find if they were the descendants of white blood-corpuscles which had escaped from the vessels with the blood, and being freely supplied with nutrient pabulum in consequence of their proximity to capillary vessels, had grown and multiplied.

We now pass on to consider more particularly how the material closing the opening in the wounded artery was produced. The facts we have observed seem to us to prove that it was formed from the blood flowing in the vessel. It appears to us that it could not have resulted from changes in an exudation poured out by the vasa vasorum, for the quantity of coagulated blood in the external coat of the artery must have so compressed these vessels as to prevent

circulation through them. And even if blood flowed slowly through them it is not easy to understand by what means the exudation could have passed through the very thick coagulum, and have reached the lips of the wound. Neither is it reasonable to infer that the lymph-like substance resulted from an exudation poured out by the elastic coats of the artery itself, for in the first place, it must be remarked that the elastic tissue of an artery is not a texture which yields coagulable lymph: secondly, the lymph-like substance covered for some distance from the wound the lining membrane of the artery which was uninjured as well as the cut surfaces; and thirdly, the material in question passed gradually into decided blood-clot. Nor are we disposed to regard this as a substance formed by the nuclei or masses of germinal matter of the elastic fibres or of the muscular fibres of the arterial tunic (although these are much more numerous than represented by anatomists), for in the specimens in question we found them only slightly larger in the neighbourhood of the injury than in other parts of the artery, while we know from other observations that where new growth is the result of the increase and division and subdivision of the germinal matter of the normal texture, vast collections of germinal matter can be traced to these bodies. In fig. 5, some of the portions of germinal matter of the artery are seen to project from the divided coats, but the corpuscles in the lymph are separated from these, and there is nothing to lead us to infer that the latter have in any way descended from, or originated in, the masses of germinal matter or nuclei of the arterial tunic.¹ On the other hand the corpuscles in question exactly resemble those found in ordinary fibrin, and they are scattered pretty evenly through the new tissue just as we should expect if they had been derived from the blood. In figs. 7 and 8 some of these bodies with the formed material (lymph or fibrin) are seen magnified 700 diameters.

With the help of the facts we have ascertained we shall

¹ Unfortunately the engraver has not rendered this drawing as well as could be wished.

now attempt to describe in the order of their occurrence, the phenomena which we think occur during the first three or four days after an opening has been made in an artery in cases where the injury is repaired. If the free escape of blood from a small wound made through all the coats of an artery be prevented by closure of the external wound, clots are of course formed in the areolar tissue and among the other textures external to the vessel, and thus the escape of blood gradually ceases. In our specimens the blood in the areolar coat of the artery was found to extend for some distance from the seat of the injury.

The opening in *the elastic coat of the vessel* is not, however, immediately occupied by blood, but, as has been shown, is gradually filled up with a perfectly colourless substance. This material, which resembles the fibrin found in some aneurismal sacs, is, like that substance, deposited from the blood layer after layer until the space is filled up. Sometimes, as in the artery represented in figs. 2, 3, and 6, the process continues until an actual elevation, projecting above the level of the inner surface of the artery, is formed.

The thin laminæ of transparent fibrin are well seen in figs. 4 and 6, and from their arrangement it is evident that they have been formed from the blood which flowed along the vessel, and not from any material poured out from beneath by the vasa vasorum or from the arterial tissues. We do not, however, regard the material as a mere deposit of fibrin from the blood, but are disposed to think that it is formed by the agency of the white blood-corpuscles, which we know would adhere to the surface of the blood-clot which occupies the lower part of the wound. It seems probable that these masses of germinal matter, as they slowly move over the surface, form the material allied to fibrin figured in the drawings.¹ This substance, it must be remembered, has been produced within three days,

¹ With reference to these supposed movements see a paper "On Contractility as distinguished from purely vital movements," by Dr. Beale, 'Mic. Journal,' July, 1864. Also 'The Microscope in its Application to Practical Medicine,' 3rd edition, 1867, p. 63.

and yet it exhibits a certain definiteness of arrangement. It adheres imperfectly to the surface of the artery, but firmly to the comparatively rough lips of the wound, and by its slow contraction it no doubt draws these towards each other. Thus we believe is formed, layer after layer, a temporary tissue, which, backed up as it is by a thick clot, is strong enough to resist the ordinary lateral pressure of the blood.

The subsequent changes taking place in this fibrin-like material which result in the permanent closure of the wounded artery have not yet been investigated. We are, however, convinced that by the method of research we have adopted, it will be possible to determine whether the new fibres which enter into the formation of the new permanent fibrous tissues, result from the masses of germinal matter (white blood-corpuscles) of the temporary adventitious tissue described by us, or from those (nuclei) belonging to the normal texture of the artery which may gradually increase in number near the cut surface of the vessel, and thus extend from this point into the temporary texture occupying the wound. There is, however, no doubt that masses of germinal matter which are the direct descendants of white blood-corpuscles do possess remarkable formative power, and observations made some time since by Dr. Beale render it almost certain that white fibrous tissue and epithelium may be formed by these. There are reasons for thinking that yellow elastic tissue may likewise, under certain conditions, result, while it is certain that the higher tissues, such as organic muscle and nerve, never originate from these bodies. Into this highly interesting and important part of the inquiry we hope to enter on another occasion.

DESCRIPTION OF PLATE VII.

The femoral artery tied for an aneurismal tumour. W. P—, æt 46. Operation, March 21st, 1867; death, April 3rd, 1867.

A. Distal portion.

B. Portion nearest the heart.