A

# PROBATIONARY ESSAY

ON THE

# FORMATION OF

# NEW BLOODVESSELS;

SUBMITTED,

BY THE AUTHORITY OF THE PRESIDENT AND HIS COUNCIL,

TO THE EXAMINATION OF THE

## Royal College of Surgeons of Edinburgh,

WHEN CANDIDATE

FOR ADMISSION INTO THEIR BODY,

IN CONFORMITY TO THEIR REGULATIONS RESPECTING THE

ADMISSION OF ORDINARY FELLOWS.

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BY

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TO

JOHN W. TURNER, Esq.

PROFESSOR OF MEDICINE AND SURGERY IN THE UNIVERSITY OF EDINBURGH;

THE FOLLOWING ESSAY

IS INSCRIBED,

IN TESTIMONY OF THE ESTEEM AND RESPECT OF

THE AUTHOR.

ON THE

# FORMATION OF NEW BLOODVESSELS.

The power of reproducing parts of the body which have been lost or destroyed, seems to be possessed in very different degrees by different classes of animals, and to vary much also in degree in the different textures of which their bodies are composed. It seems to be now fully established by observation and experiment, that the lower the place an animal holds in the scale of organization, and the more simple its structure, the more easily is the loss of any portion of its substance repaired.

In many of the Invertebrated Animals the loss of several of the more complicated organs of the body is repaired with considerable rapidity by the production of a part very similar to that lost, in form, size, and structure. The fresh-water polypus [1] (*Hydra viridis*), the star-fish [2] (*Asterias*), the sea anemone [2] (*Actinia*), various kinds of snails [3] (*Li-*

[1] A. Trembley, Mémoires pour servir à l'histoire d'un genre de Polypes d'eau douce. 4to. Leid. 1744. 4e Mém.

[2] Trembley, p. 294. C. Bonnet, Considérations sur les Corps organisés, tom. i. & ii. p. Reaumur, Mémoires pour servir à l'histoire des Insectes, tom. iv. Préface, p. lx. M. G. de Villars repeated these experiments.

[3] Spallanzani, Précis d'un ouvrage sur les Réproductions Animales

*max*), crabs, lobsters, and crawfish [1], the millepede [2], the common earth-worm [3] (*Lumbricus terrestris*), and the water-worm [4] (*L. varicgatus*), afford the best examples of this interesting process. Even in some of the Reptiles and other Vertebrated Animals, we have very striking instances of the exercise of the same reparatory power. Experiments on the tail, lower jaw, and extremities of the water-newt [5], the frog [6], and the lizard [7], have afforded to physiologists excellent opportunities of studying the reproduction of parts very different, and at the same time complicated, in their structure.

Analogous in its nature to the phenomena now alluded to, and if possible still more remarkable, is the production of two or more entire and perfect animals from the different portions into which a single animal has been purposely divided, as occurs in polypi and in the water-worm.

It has also been ascertained that the power of reproduc-

Genéve, 1778, p. 57. Bonnet's Experiments on the Réproduction of the Head of the Land-snail, in Spallanzani's Tracts, &c. Edin. 1799, p. 349.

[1] De Reaumur, Sur les diverses Réproductions qui se font dans les Ecrévisses, les Omards, les Crabes, &c. Mém. de l'Acad. Roy. des Sciences, 1712, p. 295.

[2] De Reaumur, Experiments on the "Millepied à dard." Preface to Mem. on Insects, vol. vi. p. 59. Bonnet, Considérations sur les Corps organisés, tom. ii. p. 61.

[3] Spallanzani, Précis d'un Ouvrage, &c. p. 9. Reaumur, Pref. to Mem. p. 64. Bonnet. op. cit.

[4] Spallanzani, Précis, &c. p. 23. Experiments by Lyonnet, in Reaumur's Preface, p. 56. J. G. Dalyell, Observations on Planariæ. Edin. 1814. An interesting series of Experiments on the Reproduction and Reunion of the Planariæ, has been performed lately by Mr Johnston of London.

[5] Spallanzani, Précis, &c. pp. 68, 79, and 96.

[6] Spallanzani's Experiments on the Tail of the Tadpole. Précis, &c. p. 30. Experiments on the Reproduction of the Extremities of the Frog and Toad, in Troja, De Ossium regenerat. &c.

[7] Experiments on the Eyes of Lizards by Bonnet and Blumenbach. On the Tail of the Lizard by Rudolphi.—See Blumenbach, über den Bildungstrieb.

An Account of other experiments of a similar nature is to be found in Bonnet's Traité d'Insectologie, vol. ii. Lavoisier, in the Journal des Savans, 1770. Schæffer, Versuche mit Schnecken. Senebier's Life of Spallanzani. Murray's Opuscula, vol. i. p. 317. De Redinteg. part. Cochleis Limacibusque præcisar. 1785. O. F. Muller, Historia Vermium. Experiments on the Nais proboscoidea.

ing lost parts is much greater in cold-blooded than in warm-blooded animals. In Birds and Mammalia, very few if any instances are known of the reproduction of organs of a complicated structure, or of parts of the body, such as the limbs, &c. composed of various textures; and indeed it may also be affirmed that examples of the true reproduction of individual textures in these animals are very rare and to no great extent.[1] That true regeneration of some of the textures, as for example of cellular substance, of bone, ligament, skin, nerves, and bloodvessels, is to be met with in Man, and the animals resembling him, seems now to be incontestibly proved; but, in such instances, the reproduction is very partial and imperfect, and very different from that which occurs in the lower animals.

Of all the textures of the human body the cellular seems to be the most easily and rapidly reproduced; and this substance, or one very analogous to it, is not only formed when parts of the texture itself have been destroyed or removed; but it also serves to replace some of the other parts of the body which seem themselves to be incapable of a rapid or of any reproduction.

In all these instances of the reproduction of parts of animals that had been removed or destroyed, a new substance is thrown out from the place of the solution of continuity, and this substance, sprouting out from the living surface, is gradually converted, more or less completely, into the textures, and acquires the form and structure of the part the place of which it supplies. Though there appears to be considerable variety in the animals that have been alluded to, in respect of the facility of reproduction, or the rapidity and perfection with which the parts reproduced acquire their ultimate form and structure, the mode in which this is effected

[1] A. J. Murray, Commentat. de Redintegratione partium Corp. Animal. Gotting. 1787. Otto Huhn, Comment. de Redinteg. partium Mollium in Vulnere. Gotting. 1787. Dr John Gordon, Tentam. Med. de Vulnere Naturæ Sanando. Edin. 1805.

is in many important points similar in all of them, and is very analogous to the process by which the natural growth of the same parts is carried on in the young animal or embryo.

It is also known that the reunion of separated surfaces of the textures of animals, or the healing of wounds in whatever way produced, is effected by the formation of a new substance from the living body.[1] The production of this new substance, and the process by which it is organized, so as to become subservient to the purposes of life, have many points of resemblance with the more perfect reproduction that has been already mentioned. The process of reunion may indeed be said to be nearly allied with, and to pass gradually into, that of reproduction; so that we often find it difficult to distinguish between them; and, as might naturally be expected, reunion, like reproduction, must be subject to many variations, according to the different situations and circumstances in which it takes place. Thus, for example, it is observed that reunion of divided surfaces, like the reproduction of lost parts, or of individual textures, is much more frequent, rapid, and perfect in the lower than in the more complicated animals. From circumstances connected with the simplicity of their organization, and perhaps more intimately with the structure of their nervous and vascular systems, many of the inferior animals are capable of sustaining the separation of large portions of their bodies without loss of life, or great injury, as is proved by the speedy reunion of the parts, and the re-establishment of the ordinary functions of the animal. As we ascend in the scale of animals, we find that large portions of the body cannot be separated without serious injury or even destruction of life. It appears, however, from experiments on birds and quadrupeds, as well as from observations obtained by chance in man, that the reunion of small parts that have been en-

[1] Mr J. Hunter on Inflammation and Gunshot Wounds. Lond. 1799. Dr J. Thomson's Lectures on Inflammation. Edin. 1813.

tirely separated from the body undoubtedly occurs, and that this may even be effected in parts transferred from one region of the body to another, provided the textures to be united are not very dissimilar, and that other circumstances connected with the internal condition of the individual, the state of the weather, &c. are favourable.[1] The reunion of parts entirely separated, like the reproduction of parts that have been removed, seems to take place more readily in simple than in complicated textures. In the human body, it must, however, on the whole, be considered as of very rare occurrence, and consequently the circumstances which are favourable or necessary to its success have not as yet been fully investigated.

In the higher animals, the power which divided surfaces of parts still attached to the body have of uniting with one another, is considerable; and the study of the best means of promoting such reunion, forms a very important topic of surgical inquiry. The phenomena attending the reunion of divided surfaces were comprehended under the general term of Adhesion, by Mr JOHN HUNTER, to whom we are indebted for the first systematic and philosophical account of this process, and for very valuable experimental researches into its nature. It is my intention, in the following pages, to endeavour to describe some of the more important phenomena that can be detected during the organization of the new products by which the process of adhesion is effected. In doing so, I shall confine my remarks principally to some parts of the subject that have been mentioned by systematic

[1] See the works on Reproduction and Repair already quoted; also HUNTER on Inflammation, p. 208. THOMSON's Lectures on Inflammation, p. 224. WIESEMANN, De Coalitu partium prorsus a corpore disjunctarum, Leipzig, 1824. DIEFFENBACH, Diss. Inaug. Nonnulla de Regeneratione et Transplantatione, Herbip. 1822; and also papers by him in the Journal Complément. Most of the cases which have occurred in man have been related in these works, more especially in THOMSON's Lectures and WIESEMANN's Dissertation. See also the experiments and observations of TALIACOTIUS, GARENGEOT, DUHAMEL, MURRAY, HUHN, BALFOUR, J. HUNTER, BARONIO, GRÆFE, GENDRIN, &c.

writers, as points concerning which additional information seems necessary; and I shall endeavour to explain these, as far as my opportunities will allow, by the collection and relation of such observations and experiments as have been communicated to the public in this country or on the Continent, and seem to throw light upon the subject.

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When a simple solution of continuity is produced in a vascular part of the body, without the division of any large bloodvessel, the hemorrhage which follows the division of the capillary vessels speedily ceases. The divided extremities of the capillary arteries and veins are closed, and the blood stagnates in these vessels for some little space on each side of the wound,—in each vessel generally as far as the place where the nearest considerable anastomosing branch is given off. The natural current of blood through the part is at the same time considerably changed, and some of the capillary vessels in the neighbourhood of the wound, which have not been injured, become dilated so as to give passage to a greater quantity of blood than before.

The manner in which these phenomena take place may, like the other appearances of the capillary circulation, be most easily observed in the web of the frog's foot. The hemorrhage which succeeds to a small wound of the web generally ceases about a minute after the infliction. The extremities of the arteries and veins become contracted, so as not to allow of the passage of blood; and this fluid, thus impeded, makes its way through the nearest collateral vessels, many of which were scarcely perceptible before, but now become proportionally dilated. The current of blood generally retains its original direction in the arterial branches of the capillary vessels, but it is not unfrequently changed in the veins; so much so indeed, that the blood may often be observed oscillating for a time, and afterwards taking a

retrograde course in some considerable venous branches, the easy issue from which is now in a direction opposite to that in which it formerly was, in consequence of the dilatation of other vessels in their neighbourhood, and the increased flow of blood through them.

The blood effused from the cut extremities of the capillaries becomes coagulated in a few minutes; and, if not in too great quantity, usually gives rise to slight adhesion between the edges of the wound when they are in contact; and this adhesion is in general somewhat strengthened by the drying, into a crust, of the blood which is exposed to the air at the surface of the wound.

Inflammation, or an appearance similar to it, very soon follows in the surfaces of the wound, and in the neighbouring parts; and, if this process be not too active, and unfavourable circumstances do not occur, a gradual oozing out of a clear viscid fluid takes place from the divided surfaces, termed the Coagulating, Organizable, or Plastic Lymph, which, after undergoing other changes, forms the permanent uniting medium.[1] The time at which the lymph is effused seems to vary considerably in the same and in different animals. My Father found it effused generally within four hours after the infliction of incised wounds in dogs; and Sir Astley Cooper[2] states that he generally found it effused in six hours in dogs, and in about twelve or fourteen hours in man, after wounds had been inflicted.

There seems to be little doubt that the organizable lymph consists in a great measure of the fibrinous part of the circulating blood, from which it appears to be separated by a process analogous to secretion. It is not, however, well ascertained whether the separation of this fibrinous fluid from the blood, during the state of adhesive inflammation, takes place by exudation through the extremities of cut vessels, or

[1] Hunter on Inflammation, &c. Thomson's Lectures, p. 209.

[2] Surgical Lectures, 2d edit. 1830, p. 42.

by transudation through the coats of the entire capillaries which happen to run near the surfaces of the wound. Microscopic examination does not afford us any very satisfactory elucidation of this point. In aquatic animals, the lymph has been observed to be exuded from the surfaces of wounds in the form of small flocculi, which do not seem to be accumulated in greater quantity near the extremities of cut vessels than in other places. This, along with the fact that organizable lymph is also effused from some of the textures of the body, without any solution of continuity having taken place, would seem to favour the opinion that the lymph is separated from the blood by transudation through the coats of the inflamed vessels around the wound, and is forced from these through the parenchyma[1] to the surface on which it exudes[2].

The lymph, being exuded from both surfaces of a wound, forms two layers of new substance, which coalesce when the surfaces of the wound are made to touch one another. It becomes inspissated almost immediately after its exudation, it then coagulates into a jelly, and afterwards becomes gradually firmer, and is converted into an opaque membranous substance, which forms a uniting medium of considerable consistence. At the same time, the blood which was effused immediately after the infliction of the wound is gradually absorbed, and, in the greater number of instances, wholly disappears before the union of the divided surfaces by the lymph is completed. As adhesion proceeds, the lymph becoming more condensed assumes the structure of cellular tissue; bloodvessels gradually appear in it, and it then constitutes an organized part of the animal body. The circu-

[1] The word "Parenchyma", in this and in other parts of the Essay, is meant to denote the uniform substance in which the smallest perceptible bloodvessels appear to run, and which forms therefore the interstices between these vessels. It has the appearance of a tough jelly in the web of the frog's foot, and in the fin of the fish's tail.

[2] Thomson's Lectures, p. 210.

lation of the blood is at the same time re-established through the capillary vessels in the neighbourhood of the wound, and, these forming a communication with the vessels in the lymph, the blood is enabled to pass through the reunited part, at first slowly, and afterwards as the process advances, more freely [1].

In considering the process of adhesion, it will also be proper to inquire into the mode in which lymph effused in different parts of the body, as a consequence of inflammation, and without the previous occurrence of any artificial or apparent solution of continuity, becomes organized. In these circumstances, the effused lymph frequently gives rise to the union of parts naturally separate, by a process similar in many respects to that by which the surfaces of wounds are made to adhere. The tendency to form such adhesions, it is well known, is greater in the serous membranes lining the large cavities of the body than in any other texture, and the

[1] These are the principal phenomena which occur during the process of the healing or reunion of divided surfaces, in man and most of the higher animals arrived at a state of maturity; but in the very early stages of fœtal development in the higher animals, as also in the adults of some of the lowest members of the animal scale, we meet with instances of the union of surfaces, which differ somewhat in the mode in which they are effected from what occurs in the reunion of wounded parts. I may mention as some of the most striking instances of the union of natural surfaces occurring in the fœtus, 1st, One of the very first appearances which indicate the commencement of development, viz. the coalition and subsequent union of the primitive folds of the germinal membrane, which give rise to the formation of the cavity containing the brain and spinal cord; 2d, The coalition and union of the anterior and posterior folds of the serous layer of the germinal membrane, which contribute to form the amnios; and, 3d, The junction of the double aortæ, so as to form a single vessel, seen in the ovum of the common fowl, between the fortieth and fiftieth hours of incubation. The first of these examples of union of parts in the embryo, occurs before the circulation of the blood has commenced; they are all apparently accompanied by an interstitial absorption, but no coagulable lymph seems, so far as is yet known, to be necessary for their production. Instances somewhat analogous to these occur also at a late period of development. The Polypi, Actiniæ and some other simple animals, in which there appears to be no proper circulation of the nutrient fluids in vascular tubes, furnish us likewise, when wounded, with examples of a very simple kind of union, by which their divided surfaces coalesce, without the apparent effusion of lymph, or the occurrence of any long or complicated organizing process, such as that which is observed to take place in the higher animals.

consequent union of the surfaces of these membranes affords us frequently very commodious opportunities of observing the manner in which the intervening lymph becomes organized.

It is necessary, however, to remark, that the properties of lymph as effused, either after a wound or in consequence of simple inflammation, from very different textures, are very similar. So far as has yet been investigated, no remarkable differences have been discovered in the lymph effused from any of the soft parts of the body; and it is not till after it has been effused for a considerable time, and has undergone the process of organization above alluded to, that it begins in certain parts to alter its appearance, and to partake of the peculiar properties or structure of the texture from which it has been effused,—a change which, it has been already remarked, is very slight in the greater number of the textures of the human body.

The most important, and doubtless the most remarkable part of the process of organization in the lymph effused between uniting surfaces, is the penetration of this substance with bloodvessels, and the re-establishment of the circulation of the blood through the part that had been divided. This is a gradual process, and we find considerable difference in the statements of authors respecting the time at which it takes place,—a difference depending probably on actual variations which occur, as well as on differences in the manner in which the vessels have been examined by artificial injections. Sir E. Home[1] found, that in one instance in the human body, he was able to inject the vessels of lymph effused on the peritoneum within twenty-nine hours after the commencement of the inflammation; while Sir A. Cooper[2] and Dr Gendrin[3] state, that they were not able to fill the new vessels

[1] See his work on Ulcers.

[2] Surgical Lectures, p. 43.

[3] Histoire Anatomique des Inflammations, vol. ii. Inflammations Adhésives. See also Hunter on Inflammation.

in the cicatrices of wounds till the tenth or twelfth day. Most observers seem, however, to be agreed, that appearances indicating the commencement of the formation of blood-vessels may be perceived in lymph before thirty hours after its effusion.

It seems now to be distinctly proved, that in all examples of the healing of wounds in which capillary vessels have been divided, the circulation of blood from one side of the wound to the other is re-established, not by the direct recommunication of the primitive vessels at the place where they were divided, but by the intervention of organizable lymph, and by the establishment of a communication between the new vessels formed in this lymph and the primitive capillaries. This was observed by my father to take place in wounds of the tunica conjunctiva of the eye, an instance which had previously been adduced by Mr Hunter, as a proof of the occurrence of direct inosculation of the divided extremities of vessels during reunion [1].

Most authors are agreed, that the new vessels when first formed in lymph, often appear to be unconnected with the original capillaries in their neighbourhood; and Mr Hunter, as well as several other observers, found that fine-injection-mass could not be made to pass from the larger arteries into the new vessels for a considerable time after their first appearance. But the manner in which the new vessels take their origin has been variously described by different authors; some supposing them to originate by a sort of production or prolongation of folds or loops from the uninjured primitive capillaries in the neighbourhood of the wound, and others describing them as being formed independently of the original vessels, and as commencing in situations quite isolated from them [2]. This subject has of late attracted some

[1] Hunter on Inflammation, p. 194. Thomson's Lectures, p. 213. Traver's Synopsis of Diseases of the Eye, p. 210.

[2] Drs Monro and Soemmering, in their investigations into the nature

attention, and, from the examination of the principal experiments which have been related concerning it, I think we shall be induced to adopt the last of these opinions, or that which supposes that the new vessels originate in the organizable lymph itself, and do not arise by loops from the primitive vessels or by a prolongation of their extremities, though their formation is not altogether independent of the general circulation or primitive vessels. Mr HUNTER was led by his observations to form an opinion somewhat resembling this. In observing the red isolated points that indicate the commencement of vessels in the organizing lymph, he remarked the similarity between their appearance and that of the rudiments of vessels on the surface of the yolk of the egg after about forty hours of incubation, and, by comparing these two processes, he endeavoured to explain the mode in which vessels are formed during adhesion[1]. The observations on which this comparison was founded were not, however, sufficiently extensive or minute fully to establish the analogy; and, though many authors agreed with Mr HUNTER in believing, that, in the first stage of the formation of new vessels in lymph, no connection can be traced between them and the primitive capillaries, yet many supposed that this ought to be attributed to the imperfect opportunities and difficulty of investigation, rather than to the circumstance of these vessels being really isolated; and, at the same time, some observations made by others, such, for example, as that in the conjunctiva already alluded to, seemed to give more probability to the opinion that the new vessels are formed by the ex-

of new vessels in lymph and cicatrices, established by artificial injections, the fact of their connection, when fully formed, with the primitive vessels. Dr MONRO has represented the new vessels in lymph effused on the peritoneum of the pig, which were filled from the epigastric arteries, and Dr SOEMMERING injected the new vessels on false membranes of the pleura from the intercostal arteries. These facts had also been established by the experiments of DUHAMEL and HUNTER.—*See* MONRO *on the Nervous System, Plates* 46 and 47.

[1] HUNTER on Inflammation, p. 92.

tension of loops or folds from the original vessels on the sides of the wound. As additional researches have been made on this minute and difficult subject, the opinion of Mr Hunter has gained ground, and his description of the formation of new vessels has been closely followed by several systematic writers, as Meckel [1], Beclard [2], and Lobstein [3].

Dr Gruithuisen of Munich seems to have been the first who applied the microscope with sufficient minuteness to the investigation of the formation of new vessels in the transparent parts of animals. The observations of this physiologist, which were made on the tail or fin of a mud-fish (*Cobitis fossilis*), seem to confirm the views of Hunter [4].

Dr Gruithuisen found that, when a part of the tail of the fish was wounded or highly stimulated, the capillary vessels in the neighbourhood, after being much dilated, again contracted gradually to an unusual degree, and only a few of the largest continued to give passage to blood. After the flow of blood through the inflamed part had ceased for some time, he observed, in the tissue occupying the interstices of the primitive capillary vessels, the appearance of a number of red points which he believed were produced by the deposition of "amorphous blood-globules." These points, when observed for some time, were seen gradually to enlarge, to acquire a linear, and sometimes a serpentine shape, and to throw out at their sides radiated striæ, which, by their union with similar striæ proceeding from other points, gave rise to

[1] Meckel, Handbuch der Pathologischen Anatomie, vol. ii. part 2d, p. 30, &c.

[2] Anatomie générale, p. 331, and his Additions à l'Anatom. génér. de Bichat.

[3] Elémens d'Anatomie Pathologique, p. 297.

[4] These observations are frequently referred to by German writers. They were first published in the Salzburg Medizinische Zeitung, vol. ii. 1811. A short account of them is given in Gruithuisen's Organozoonomie, Introduction, p. 6, Munich 1811, from which the extract in the text is taken; and also in his Beyträge zur Physiognosie und Eautognosie, in which work they are illustrated by Plates. See also Langenbeck's Nosol. und Therap. der Chirurg. Krankheit. vol. i.

small undefined bloody chains and networks. He found that, in many places, these striæ also gave rise to new capillary vessels, wider than the old ones, and frequently occupying different situations, and distributed in different forms and directions from them, but in such a manner, that, taken altogether, they supplied the place of the original capillaries. Dr Gruithuisen informs us that the blood remains stagnant in these new vessels, till a communication is established between them and the primitive capillaries which are pervious; and, in cold-blooded animals, this sometimes does not happen for hours, or even days. When this communication is effected, the blood moves through the new vessels, at first very slowly, afterwards more quickly, and they thus come to constitute a part of the general circulation. Dr Gruithuisen states, that he has observed that the new vessels are produced in a similar manner in lymph that has been effused on the surfaces of wounded parts and of inflamed serous membranes. The works in which these observations are related, and the style in which they are described, are rather too theoretical to enable us to place entire confidence in their accuracy: they receive, however, considerable support from the descriptions given of this process by Meckel and Lobstein, as well as from detached observations related by Hastings [1], Bichat, Laennec and others.

Dr Gendrin made a number of experiments on the process of adhesion of wounds, by raising flaps of the skin of animals, and then replacing them so that they might reunite [2]. There is considerable variety and ingenuity in these

[1] Dr Hastings, in describing the appearances which presented themselves after wounds of the frog's foot, states that the surfaces of the wound were covered with a dense white matter on the second day. On the third day, there were seen in the white substance small vessels, through which, on the fourth, the blood was observed to move slowly. On the eighth, the blood circulated freely. The opposite edges of the wound were united together by the newly deposited substance, which was nearly as vascular as the other parts of the web, and its vessels communicated freely with that part of the web on which it was deposited.—*Treatise on the Inflammation of the Mucous Membrane, &c. Introduction*, p. 87.

[2] Histoire Anat. des Inflammations. Paris 1826, tome ii. p. 357.

experiments, but it is to be regretted that Dr Gendrin has neglected to inform us on what animals they were performed, and in describing them, has made no reference to the observations of those who preceded him in the investigation of the same subject; so that, in reading his Treatise, it is impossible to distinguish between what is intended to be given out as new and what he conceived to be already well ascertained; and it is equally difficult in many parts to find out whether he is announcing a general proposition or describing a particular fact.

Dr Gendrin observed the formation of vessels in organizing lymph to be preceded by the appearance of isolated points and broken lines; but he attributes the origin of these new vessels, somewhat theoretically, to the propulsion of blood from the natural orifices of the primitive capillaries, and the hollowing out of irregular passages in the least resisting parts of the lymph by a *vis a tergo*, composed of the force of the heart and arteries, " and, in the venous vessels, of the peristaltic action of the absorbing capillaries[1]." This opinion of Dr Gendrin is founded principally on observations which he made on the organization of lymph effused on the surfaces of the pleura and peritoneum. These observations are related in his chapter on the Pathological Anatomy of False Membranes, and form a very interesting part of his treatise[2].

Dr Gendrin describes the formation of vessels in pseudo-membranes as being preceded by the occurrence of a kind of cellular arrangement of the substance of the organizable lymph, and by the firmer adhesion of this lymph to the serous membrane with which its vascular connection is first established. He observed that the parts of the serous membrane at which the lymph adhered most strongly, were rendered very red by the increased number and greater dilata-

[1] Hist. Anat. des Inflam. vol. ii. p. 365.

[2] Ib. p. 550.

tion of the capillary vessels of the membrane, and that from these vascular spots small red cones were to be seen projecting into the lymph. On examining these cones with a microscope in the living animal [1], Dr Gendrin observed that that part only of the lymph which adhered to or was next the serous membrane, was vascular, and that the small vessels which are formed in the lymph appear in the early stages of its organization like yellowish striæ, which some time after their formation, begin to carry red blood for a little way from the serous membrane into the lymph, giving a red appearance to the portions through which they pass, while the rest of the striæ, and the other parts of the lymph and striæ, not being penetrated by blood, still remain yellowish or colourless. Dr Gendrin farther states, that he has observed that the vessels, when first formed in lymph, are so small as to admit not more than one globule of blood at a time, and this only at intervals of a second or so; and that the larger vascular trunks in the lymph, in which he has observed the motion of the red globules to be uniform, are produced by the union of several of the smaller ones during the process of organization. The vascular striæ, according to Dr Gendrin, are generally straight, but some of them give off lateral branches: they are smallest and most subdivided at the place where they pass from the serous membrane to the lymph; they are larger in the interior of the lymph, and, when completely formed, as on the eighth or tenth day, may be easily filled with mercury. According to this author, it is the existence of these comparatively larger vascular striæ, which are easily visible with the naked eye, that has given rise to the opinion that, in the repair of wounds, vessels are formed in lymph isolated from and independently of the primitive vessels, in the same way as takes place

[1] Dr Gendrin made these observations on the mesentery and peritoneum of a living Guinea-pig, in the abdomen of which inflammation had been excited, six or seven days before, by the injection of a saline fluid.

before the commencement of the circulation on the surface of the yolk of the egg.

Dr Gendrin does not appear to have observed in what manner veins are formed in lymph; but he thinks it probable that the vessels already described as shooting outwards from the serous membrane into the lymph, and which are to be regarded as of an arterial nature, give rise to returning branches or veins by a process similar to that by which they themselves are formed [1].

Dr Gendrin found, in his experiments on raising flaps of skin, that, from the stagnation of blood in the neighbourhood of the wounds, mercury injected into the larger vessels could not be made to reach the surface of the wound till about the twelfth day: in a few days afterwards, it could be made to penetrate the organizing lymph; and about the 20th or 25th day, but not before that time, it could be made to pass through the organized lymph or cicatrix into the flap which was reunited. He found that the mercury invariably penetrated the substance of the cicatrix for some time before it could be made to pass through it into the flap. Professor Turner of Edinburgh has casually observed injection-mass to enter the vessels of organized lymph on the surface of the pleura pulmonalis and pericardium covering the heart, although these have not adhered to the opposite serous surfaces; —which observations, as well as many others, seem to shew, that the opinion of Prof. Schroeder van der Kolk [2], that the vessels of false membranes are not permeable, till after they become united with the vessels of the membrane on both sides, is erroneous.

[1] MM. Laennec and Gendrin suppose that the coat of the new vessel in organizing lymph is produced by the propulsion of blood into the new spaces or striæ formed in the lymph, and by the subsequent adhesion of the globules of the blood to the sides of the vascular space, &c.

[2] Observationes Anatomico-pathologici et practici argumenti. Amstel. 1826. Fascic. 1. Introd. Several preparations in the Museum of the College of Surgeons, Edinburgh, illustrate this very well.

The most complete series of microscopical observations on the formation of new vessels that has hitherto been published, is contained in a Dissertation by Dr Kaltenbrunner, on the state of the Blood and Vessels during Inflammation[1]. The observations of this author on Adhesion, Suppuration, &c. made on the web of the foot and on the mesentery of the frog, on the tail-fin of the mudfish, on the gills of the water-newt, on the mesentery of rabbits and mice, and on many other parts of these and of other animals, though mixed up with much theory and new nomenclature, and by no means described in a clear style, must be considered as a valuable contribution to our knowledge of these subjects, and seem to render the isolated origin of bloodvessels in lymph very probable.

The researches of Doctors Gruithuisen and Kaltenbrunner concerning the mode in which vessels are formed in adhesive inflammation, derive additional support from the investigation of the growth and development of vessels in the state of health. The very beautiful observations of Harvey, Wolff, Pander, and others, have long ago shewn that the blood and vessels appear simultaneously in the vascular area of the yolk in the incubated egg, and that their origin is, to a certain extent, independent of that of the heart and general circulation. It is now well known that those vessels in which the first circulation begins, exist, though in a somewhat imperfect condition, and contain a fluid which afterwards becomes blood, before they directly communicate with the heart, and before motion commences in that organ; and it is therefore obvious, that the formation of the vessels does not, in this instance, depend on any impulsion, or *vis a tergo*, from the heart.

Spallanzani[2] appears to have been the first who made

1 Experimenta circa statum Sanguinis et Vasorum in Inflammatione, cum 9 tab. Monachii, 1826.

2 Experiments on the Circulation of the Blood, translated by R. Hall, M.D. Lond. 1811.

similar observations on the formation of vessels at a more advanced period of the growth of the fœtus and young animal. The interesting researches of this ingenious physiologist, together with those of Fontana [1], Rusconi [2], and Dœllinger [3], on the capillary circulation as seen in the transparent parts of Batrachian Reptiles and Fishes, have furnished us with materials by which to establish a comparison between the phenomena of the natural production of vessels and those of their development during the healing process [4].

[1] Uber das System der Evolution. in Reil's Archiv fur die Physiol. B. ii. p. 480.

[2] Amours des Salamandres Aquatiques et développement du Tétard, &c. Also in his description of the organs of circulation in the larva of the same animal,—and in his last work, Sur le Développement de la Grenouille commune.

[3] Denkschriften der Konigl. Akad. der Wissenschaften zu München, B. vii. translated in the 'Journal des Progrès des Institut. et des Sciences Médicales,' vol. ix. 1828, p. 70.

[4] Some observations made by Spallanzani, and described in his Essay on Animal Reproductions, are so interesting, and seem to bear so directly on the present subject, that I shall quote the principal results. (Précis, &c. p. 28, 31.)

In making sections of the tails of very young frog-larvæ, Spallanzani found, that the quantity of parts reproduced was generally proportional to the size of the portion removed, till he cut as far as the middle of the tail, when the force of reproduction did not seem sufficient to renew the whole with such rapidity as it did when a smaller piece was cut off. —"If the tadpoles are yet young," he observes, "we discover the part newly produced very soon after the operation. In a fine summer day, it makes very rapid progress, and the tail soon acquires the same size as it had before it was injured. The tail, when beginning to bud, on being observed in the microscope, presents the appearance of a central portion corresponding to the muscular part, and two lateral membranous parts corresponding to the fin: these are at first very small, and form a sort of pyramidal elevation from the surface of the wound. The blood does not at first enter this substance; but all the blood which descends by the large artery of the tail, the aorta, is discharged into the vena cava by small collateral branches in the stump. At a later period, the blood from the artery passes the limits of the section, and advances a little way into the middle of the reproduced fibres, but soon returns into the stump, where, being divided among several small branches, it passes over into the large vein. In proportion as the reproduced part increases, the large artery advances farther into its substance, and dividing into a considerable number of small branches, supplies all the parts of it with blood. These branches are prodigiously multiplied in a single day: the greater part of them go as far as the end of the tail, and then return to the stump, being at the same time changed into veins, which having passed through the repro-

The researches of these observers on the natural process by which vessels are developed in young animals, have shewn that the parenchyma, or formative tissue, from which the principal organs spring, does not at first contain bloodvessels, —that the vessels, when first formed, are very thinly spread over the formative tissue,—and that they gradually increase in number and in the complication of their distribution as the animal advances to maturity. It has been found that the new vessels thus added to the primitive ones, have at first the form either of small vascular loops connected with the primitive trunks, or of nearly straight cross branches extending directly between their arterial and venous parts. These new vessels, like those formed in organizable lymph, have been supposed by some to be prolongations of the original vessels; but it has been observed, that the original trunk still remains continuous, and occupies the same place, while the new vascular portions appear in the neighbouring parenchyma. Spallanzani and Fontana, again, suppose that these new passages through the parenchyma are produced solely by the action of the *vis a tergo* communicated by the heart or arteries; but some very minute observations by Professor Dœllinger seem to offer another explanation of the phenomena, and to indicate, that, if the circulation in

duced parts, pour their blood into the large vein. These branches, arterial as well as venous, gradually increase, so as to carry blood more and more abundantly to all the parts of the new-formed tail. Hence there arises a remarkable difference between the circulation in the natural and in the reproduced tail. In fact, though the central artery and vein in the old tail give off several branches in their course, yet they always remain larger than the rest of the vessels, and preserve their original direction; but the vessels newly produced divide into an infinite number of small and tortuous vessels, distributed irregularly over the whole of the reproduced part."

Spallanzani has made similar observations on the reproduction of the tail and other parts of the Salamander; and of the dorsal vessel in the Freshwater Worm or Lumbricus variegatus.

Some good observations on the natural formation of new vessels are to be found in Burdach's 'Physiologie,' vol. ii. p. 506; also in Baer's History of the Development of the Chick, in the same work, vol. ii. p. 239; and in the 'Répertoire générale d'Anat. et de Physiol. tom. viii.'

the new vessels is really immediately produced by such an impulsion, or if these vessels become first clearly visible by the injection of blood from the artery into them, some preparatory process of organization or development takes place in the parenchyma, by means of which the course which the blood takes, when thus impelled, is determined.

The observations of Professor Dœllinger on the capillary circulation and on the natural growth and multiplication of vessels, were made on the transparent parts of the embryo of a kind of Dace (Leuciscus), which he found accidentally detained in the gills of the large Freshwater Mussel (Unio), and are described in a memoir in the Transactions of the Royal Academy of Munich. Prof. Dœllinger concludes from his researches, that in the natural process of growth new vessels are formed chiefly in two ways: 1*st*, By the blood, impelled from the original vessels by the vis a tergo of the heart and arteries, hollowing out passages in the parenchyma or formative tissue, which are gradually converted into vessels; and, 2*d*, By the development of canals in this tissue, independently of the action of the heart or arteries,—in the way, in fact, in which Mr Hunter supposed vessels to be generated.

1. In watching the development of the small fish-embryo, Professor Dœllinger frequently observed globules of blood to make their escape from a capillary vessel, and to be projected into the neighbouring parenchyma: he found that these globules sometimes remain stationary in the places into which they have been thrown, but that in other instances, —and this is what occurs most frequently in young fishes, —they continue to move onwards in the parenchyma until they meet with some other capillary branch into which they drop. He states that other globules are seen to succeed to the first, and to pass through the same course which it took; more afterwards follow, and at last the formation of a new capillary vessel in the line of these globules is completed by the passage of a continuous stream of blood through it. Dr

Kaltenbrunner[1] states, that he has observed this to happen very rarely indeed in the adult animal, at least in the tail of the Cobitis or in the web of the Frog's foot. It may be said, and in some instances perhaps not without reason, that the globules, supposed to have formed new passages in the manner described, only entered vessels which previously existed, but were so small as not to admit the red particles of the blood, and were consequently invisible. This undoubtedly often occurs in the adult animal in morbid alterations of the circulation. The supposition of previous existence, however, is one which may be applied to all the organs which are formed in the fœtus. At the same time, it must be allowed by all, that, during the growth of the animal, vessels actually make their appearance which were not before susceptible of dilatation by inflammation or other causes; that this does not take place indiscriminately at all periods of life, but seems chiefly to be confined to the early stages; and that the new passages which come thus to admit the red globules continue to do so ever afterwards, and form, in fact, permanent vessels, some of which, in the progress of growth, increase greatly in size, and become connected, in their turn, with other new vessels developed in the parenchyma near them. It may be remarked, however, that the very regular, constant and determinate course which the vessels of animals hold, in various circumstances of deformity and change, seems to render the supposition of their being developed solely by the impulsion derived from the heart and arteries very improbable, and to shew that some change in the parenchyma itself must precede the impulsion of the globules into it: and, as M. Burdach[2] has justly observed, there are some instances,—more especially in the early stages of the development of the fœtus, but consi-

[1] In an Essay appended to the Translation of Professor Dœllinger's, in the 9th vol. of the Journal des Progrès, &c. 1828.

[2] Physiologie, vol. ii. p. 512.

derably later than the period of the formation of the heart and the establishment of the circulation,—in which the formation of vessels occurs in a direction contrary to that in which the propelling power of the heart acts. The formation of nearly the whole of the veins may be quoted as one of these instances, as well as the subdivision which occurs in the vena portæ in the first stages of the formation of the liver. That some change occurs in the parenchyma seems to be rendered still more probable by the account given by Professor Dœllinger of the second mode in which he conceives new vessels may be developed.

2. Professor Dœllinger observed the formation of vessels in the isolated way to commence by a kind of softening or liquefaction of a part of the parenchyma near to the primitive vessels, which may be seen over the whole of the finny tail of the fish-embryo, but is most easily observed towards the end of it, near the place where the large artery, the aorta, bends round to form the vena cava. He states, that in the vicinity of a primitive "current of blood,"[1] or capillary vessel, a stria of the parenchyma becomes gradually fluid, and enters into motion; and there is thus formed a small column, as it were, composed of mucous corpuscles, one extremity of which nearly reaches the primitive capillary, while the other end is farther removed from it. This fluid stria or column moves regularly backwards and forwards, approaching to and receding from the current of blood in the primitive capillary; the mucous granules of which it is composed gradually assume a more determinate form, and become oval; and at last the oscillating mass divides itself into two small currents, one of which moves in an arterial, the other in a venous direction: the two ends of the oscillating line approach gradually nearer to the primitive vessel,

[1] Professor Dœllinger supposes that the small capillary vessels in which this process takes place are destitute of proper vascular parietes, and are merely passages through the substance of the parenchyma.

and at last unite with it in the form of an arch or bow. Professor Dœllinger seems to think that the end of the oscillating line, or new vessel, which is next the *arterial* part of the primitive trunk, is first joined with it; he has remarked, indeed, that globules projected from the primitive artery may sometimes be seen to enter this end of the new vessel, before the period when the blood passes freely through it. Immediately after the union of the new vessel with the primitive trunk, the motion of the globules through it is slow, and there is subsequently a gradual increase in the velocity of the circulation, as well as in the diameter of the vessel, till the new loop comes to resemble in all respects the primitive capillaries with which it is united. The complete formation of vessels in this way occupies a considerable time: Professor Dœllinger has observed the oscillating motion to continue during forty-eight hours in a very young embryo of the fish.

The new vessels in the fish-embryo are at first developed from the sides of the primitive vessels of the tail, viz. the prolongations of the aorta and vena cava, which are at first the only vessels that carry blood to the tail. The new formed vessels gradually extend from the central line of the tail to the lateral finny parts: this extension does not, however, appear, so far as has yet been observed, to be the result of the elongation of the trunks of the primitive vessels, but of the successive development of new vessels farther and farther from the central line. At the same time it must be remembered, that the new vessels undergo that elongation which is necessary to enable them to maintain their relative size and situation during the general enlargement of the whole tail. Each of the new vessels, when first formed, has generally the appearance of what may be strictly called a capillary—that is, a vessel in which the flow of the blood is generally uniform, and which extends between an arterial vessel, in which the blood moves onwards from the heart in jerks, and a vein,

in which the blood moves in a uniform stream, backwards to the heart. The character of the circulation through the new vessel varies much, however, according to the place in which it is developed. In many instances the blood moves in jerks through the whole or a part of the new loop of vessel, giving it the character of an artery. As new loops are again developed from the new formed vessels, those parts of these vessels which receive the blood from the primitive arterial trunk become larger, and assume more of the arterial character, while those parts of them in which the blood makes its exit in returning into the primitive venous trunks, also enlarge and take on a strictly venous appearance. Thus, the new vessels, which at first form only part of a capillary net-work, are converted into larger arteries and veins.[1]

In the dissertation by Dr KALTENBRUNNER already referred to, this author states that he has, like DŒLLINGER,

[1] Dr KALTENBRUNNER's observations on the formation of new vessels in the embryo, correspond very nearly with those of Professor DŒLLINGER, both as regards the position of the new loops of vessel relatively to the old ones, and the oscillating motion that accompanies their formation. Dr KALTENBRUNNER, however, states it as his belief that the newly formed loops are united with the original vessel at the *venous* part, before any blood is driven into them from the artery.—(Separate Memoir by Dr KALTENBRUNNER, Journal des Progrès, 1828, tom. ix, p. 37.) Observations somewhat similar to those of DŒLLINGER and KALTENBRUNNER, were related by Dr BAUMGAERTNER of Freyburg to the Naturalists met at Heidelberg in 1829, in an Essay on the Influence of the Nervous System on the Motion of the Blood (now published in the Isis for 1830, p. 595.) Dr BAUMGARTNER states, that he has observed that, at the time when the tail of the small frog-larva becomes transparent, but while there is yet no circulation of blood in the finny part of it, the granular substance of which the tail is composed is arranged in the form of dark striæ, which arch outwards from the thick fleshy part in the middle. In examining one of these striæ very minutely, Dr BAUMGAERTNER saw, from time to time, a granule slip from the stria into the dorsal vessel in which the blood was moving backwards towards the heart. All the granules in the arched stria gradually moving away, the whole of the shaded stria became quite clear, and a vascular channel was formed, through which the globules of the blood immediately passed. According to these observations, then, the granules from the parenchyma of the tail enter the vein first, and thus give rise to the channel or new capillary vessel into which the blood-globules are propelled from the neighbouring artery by the action or *vis a tergo* of the heart. Dr BAUMGAERTNER does not mention his having observed any oscillating motion during this process.

observed that new vessels are formed in the lymph effused on the surfaces of a wound, as well as in the natural process of growth, in two ways, viz. 1, by the projection of globules of blood from the primitive vessel and the consequent generation of a loop of new vessel by the *vis a tergo*; and 2, by the formation of isolated points and lines in the lymph or in the intervascular spaces of the parenchyma.

With regard to the first of these processes, Dr KALTENBRUNNER states[1] that, a short time after the deposition of the organizable lymph on the surfaces of a wound, he has observed some opaque spots to appear in the intervascular spaces and in the lymph, which seem to be caused by the effusion of a reddish fluid: these spots generally soon become of a rounded and more circumscribed form, and granules appear in the fluid which fills their cavities. After the formation of these granules, the figure of the cavity is gradually changed from round to oval; and, at the same time, an obscure motion of the granules takes place in the interior. The canal or channel occupied by the granules continues to elongate, and forms a crescentic line, the concavity or two cornua of which are turned towards the cut extremities of the old vessels. The colour of the fluid and of the granules becomes deeper as the extent of the channel increases and the granules become more apparent; the motion of the granules also becomes more obvious, and they may be distinctly seen to oscillate for a considerable time, and the cornua of the crescent continually advancing, at last reach the trunk of the primitive vessel. When the stagnation of blood, which generally occurs, after a wound, in the greater number of the neighbouring vessels, has ceased, and the blood again flows into them, the globules from the oscillating crescentic channel escape, or are driven from the lymph into the venous part of one of the primitive vessels; and the blood from an arterial branch, coming after them, establishes

[1] Experimenta, &c. p. 24. to 30.

a complete passage through the new loop. The new piece of vessel thus formed constitutes a loop which supplies the place of an anastomosing branch between an artery and a vein.

Dr Kaltenbrunner states that, at other times, the blood from the arterial part of the primitive vessel is propelled into one extremity of the new loop, and, after traversing it, forces its way irregularly through the parenchyma, and either joins the first primitive vessel it meets with, or unites with other oscillating lines, and, pursuing an irregular course, thus gives rise to a long and flexuous vessel.

The formation of these new loops of vessels takes place, it will be understood, in the lymph effused on both surfaces of a wound, and, after the completion of the loops of new vessels, blood is thus propelled from the primitive capillaries through the loops on each side. At first, therefore, the blood, which is driven outwards from either of the surfaces of a wound, returns to the veins on the same side; but when the two layers of organized lymph are brought together, and complete reunion takes place, it is well known that the new vessels from the opposite sides also unite and inosculate with one another, so as to allow of the circulation of blood or the transmission of artificial injections entirely through the new matter which forms the uniting medium or cicatrix. It does not, however, seem to have been ascertained whether this inosculation is effected by the union of such lateral loops as have already been described, or by the formation of other new vessels, which subsequently serve to unite the loops of the two sides.

The researches of Dr Gendrin,[1] already quoted, and some others made by Professor S. Van der Kolk,[2] of Utrecht, have led these observers to believe that, in the organizable lymph effused on the surfaces of inflamed serous

[1] Hist. Anat. des Inflam. tom. ii. p. 550.

[2] Observ. Anat. Pathol. et Pract. Argum.

membranes, the new vessels do not appear in the form of loops from the adjacent primitive vessels, but as single tubes extending from the serous surface into the lymph. In a specimen of very finely injected organizing lymph on the surface of the pleura, which I received from Dr Pockels [1] of Brunswick, I find that the new vessels are disposed in clusters or bundles of innumerable very small tubes projecting into the lymph from the serous membrane. The greater number, however, of those which are perfectly formed, are obviously composed of a long loop or double vessel, joined at the distal extremity; while the injection-mass has also passed into other tubes which have not the appearance of loops, and into many small irregular spaces which are connected with the more perfectly formed vessels.

From the researches of Professor S. Van der Kolk it also appears that, after the union of the organizable lymph on both sides with the serous membrane, some farther change in the disposition of its vessels occurs. This observer found that, when injection-mass was made to enter the vessels of the serous membrane on one side, as, for example, when it was injected into the pulmonary artery, it passed entirely through the vessels of the lymph, and entered the arteries on the other serous surface, or the intercostals. The same takes place, according to this author, in the venous trunks, but very little of the injection passes, within the lymph, from one set of vessels to the other, from arteries to veins, or *vice versa*. The new vessels in the lymph effused on serous membranes, are sometimes very long; they are generally fewer in number, and larger, in the middle part of the lymph than at the sides, and are much subdivided at their extremities where they join with the primitive vessels: from this

[1] It is to be regretted that Dr Pockels' Observations have not yet been given to the public, as his collection of fine injections of organizing lymph, as it appears in healing wounds, granulating sores, and on the serous membranes, forms one of the most extensive and illustrative series of preparations of this kind in existence.

circumstance, MECKEL, BECLARD and S. VAN DER KOLK, have compared them to the vena portæ, or a new vascular system formed by the division of bloodvessels of one description.

It would appear that new vessels are also occasionally developed in the parenchyma of organs, without any apparent division of the primitive vessels, such as happens in a wound. This generally occurs in the inflamed parenchyma, near wounds or injuries produced by ulceration, gangrene, &c. In such situations, it appears that there is generally a considerable quantity of lymph effused into the parenchyma, which is not afterwards removed by absorption, as serum or pus are, but forms a dense texture, which is penetrated with bloodvessels, and affords strength and protection to the destroyed surface. On the margins of transparent parts which have sphacelated, as in the web of the frog and tail of the fish, Drs GRUITHUISEN and KALTENBRUNNER have observed the formation of vessels to take place in isolated spaces of the parenchyma, much in the same way as in the organizable lymph effused on the surfaces of wounds in the state of adhesive inflammation.

Difficulties similar to those which occur in explaining the organization of lymph in simple adhesion, have arisen respecting the mode in which vessels are formed in the lymph effused during the process of healing by Granulation[1]. The organizable lymph is frequently effused in the form of successive layers on the surfaces of wounds tending to granulation; and it appears that of these layers, that first deposited or situated next the living part, is first organized or penetrated with bloodvessels. Though this is the case, it does not appear to be ascertained that the new vessels are formed by the extension of vessels already existing, or by the impulsion of the heart. The punctuated and stellated appearance of

[1] HUNTER on Inflammation, &c. p. 477.—THOMSON's Lectures, p. 404.

these new vessels, at the period of their first commencement, would seem rather to shew that they are developed in isolated situations in the lymph composing the granulations, and that they are united by a secondary process with the primitive vessels, as happens in adhesion. It is well known that the vascularity of the texture which forms the base of the granulating sore, is much increased by the dilatation of the old and the formation of new vessels. Mr Hunter has described the vessels of granulating sores as shooting up from this vascular base into the lymph which is effused on its surface, and which constitutes the granulation. He observed, in one instance, in which he had scraped off the external surface of a bone of the foot that had been denuded, that a whitish substance covered the denuded part on the next day, and, on the succeeding day, this whitish substance was filled with bloodvessels, and had the appearance of healthy granulations. My father found, by artificial injections, that the new vessels rise from the vascular base into the substance of the granulations in the form of thick clusters, and that each of these clusters of vessels frequently consists of a larger or principal vessel, subdivided into smaller branches, which, forming loops, inosculate with one another at the extremity of the granulations[1]. In a beautifully injected specimen of granulations from a sore in the leg, which was given me by Dr Pockels, I find that the vessels which are completely formed in the granulations have all the form of loops at their distal extremities, while, at the same time, in several of the larger granulations, a principal vessel, dividing into smaller branches, is easily seen; the smaller branches formed by the subdivision of one of these principal vessels, unite at their extremities, or pass over, in the form of loops, into those of another large trunk, thus shewing that these two large ves-

[1] Lectures on Inflammation, p. 406.—See also Sir A. Cooper's Lectures, p. 71, in which this account of the structure of the vessels of granulations is fully confirmed.

sels bear to one another the relation of artery and vein, while their smaller twigs may be regarded as true capillaries.

We might have been led to suppose that the structure of vessels formed in this manner, would vary much according to the nature of the texture in which the granulations are seated; but, so far as has yet been observed, this does not appear to be the case. There is, on the contrary, the greatest similarity in the structure of granulations, and in the arrangement of the vessels supplying them with blood, in parts that differ much in their structure, and in which the distribution of vessels is naturally very dissimilar;—a circumstance which, taken along with the fact, that no very obvious difference is to be seen in the organizable lymph effused from different textures, seems to support the opinion that the new vessels in granulations are formed in an isolated manner in the lymph.

When the opposite surfaces of granulating wounds are brought together, they soon adhere, and the vessels in the granulations on each surface inosculate with one another, so as to allow the transmission of blood through the new substance between the reunited surfaces, much in the same way as happens in the simple adhesion of wounds: the granulating form of the lymph seeming, in this process, to constitute the chief distinction between the organization of lymph in healing by the first and by the second intention.

As the process of adhesion proceeds, in simple or in granulating wounds, the number of new vessels increases: the new vessels are in general considerably larger in diameter than the primitive branches with which they are connected; and, in the re-uniting medium of wounds, healed either by direct adhesion or by granulation, they are frequently so numerous, and so much distended with blood, that their structure or distribution is scarcely recognisable. As the healing process becomes perfected, however, the vascularity of the newly produced substance greatly diminishes, the vessels be-

come considerably contracted, and many of them become so small that they seem even to disappear, or at least to cease to carry red blood globules; and this contraction takes place to such a degree, that the healed part, or cicatrix, is generally, in after life, less vascular than the parts which it unites. At the same time, the cellular texture resulting from the organized lymph becomes much denser, and it may be inferred, from the absorption which occurs on large cicatrized surfaces of substances applied to them, and from the delicate sensibility these surfaces possess, that this new texture is also supplied with absorbent vessels and with nerves. It seems, however, somewhat doubtful if organized lymph, and especially granulations, are supplied with lymphatic vessels, at so early a period as by some has been supposed. The absorption of substances, from so soft and spongy a texture as that of which granulations consist, can scarcely, I should conceive, be considered as a decided proof of the presence of absorbent vessels; though, at the same time, the mercurial injections of Professor S. Van der Kolk seem to prove their existence in pseudo-membranes of long standing upon the pleura[1]. The phenomena attending the reunion of parts which have been entirely separated from the body, as well as those which accompany wounds of the nervous texture itself, shew very decidedly that nervous substance is capable of being reproduced. This, however, occurs only in small quantity, and by a tardy process; and the apparent acute sensibility of the granulations on the surfaces of wounds or sores, probably arises from their being seated on the denuded filaments of nerves.

Before leaving this subject, it seems necessary to allude shortly to the opinion that has been held by some, that blood is capable of becoming organized, and of having vessels developed in it. This, which was the opinion of Mr J. Hunter, was called in question by my father, and the ob-

[1] Observ. Anat. Path. &c.

jections to it were stated by him at considerable length in his Lectures on Inflammation.

The circumstances of the colouring matter of the blood being absorbed, when a coagulum of this substance remains long in the body,—of coagulated blood often presenting some appearance of regular structure,—and of organizable lymph being frequently tinged by, or even mixed with blood extravasated in its vicinity, appear to be the phenomena which have led many surgeons to believe in the possibility of blood becoming organized. The facts that the blood effused between the surfaces of a wound is generally absorbed during the process of healing, and its place supplied by exuded organizable lymph,—that when the blood is not thus absorbed, it generally forms a hinderance to the process of adhesion,—and that in those situations in which effused blood remains long in the body, in circumstances, so far as we know, not unfavourable to organization, as, for example, in aneurismal sacs or apoplectic coagula, no organizing process takes place, seem to render the opinion, that simple blood is capable, by its coagulation, of becoming an organized medium of union between divided parts, and of being penetrated with blood-vessels, very doubtful indeed. At the same time, it is possible that, by the effusion of organizable lymph around and in the substance of coagula of blood, their entire removal may sometimes be prevented, and the fibrinous portion of the blood, deprived of its colouring matter by subsequent absorption, may perhaps be incorporated with, or become part of, an organized texture. So far as I know, no satisfactory case of the permanent organization of a coagulum of blood, altogether free from lymph, has been recorded [1].

[1] Though Mr Hunter's view has been adopted by several authors of eminence, Sir E. Home is, I believe, the only one who has endeavoured to support it by any considerable series of experiments. In the Croonian Lectures, "On the Changes the Blood undergoes in the act of Coagulation," and "On the Conversion of Pus into Granulations of New Flesh," published in the Phil. Trans. in 1818 and 1819, he has advanced an opinion, that

The observations related in the course of the preceding pages, seem to shew that a great analogy exists between the process by which lymph that has been effused in the adult animal, in consequence of inflammation or division of parts, becomes organized, and that by which the vascular system of young animals is developed. The following general conclusions may be deduced from these observations:

1. The origin of the circulating organs in the fœtus takes place by the isolated, gradual, and simultaneous formation of a blood-like fluid, and of vascular spaces on the yolk of the ovum.

2. After the vascular spaces or commencing vessels become united with the heart, and the circulation of blood is established in a certain number of them, the new vessels, which are subsequently produced in the progress of growth, appear in the form of small loops or canals, which pass between different primitive vessels, or from one part of a primitive vessel to another. These new vessels are at first of the nature of capillaries, but as others are developed from them, part of them gradually becomes venous, and part arterial; in short, they are converted into arteries and veins.

There is great reason to believe that some change, or pre-

the formation of vessels occurring during the organization of blood, lymph and pus, all of which fluids he seems to believe to be capable of becoming organized, is produced by the extrication of carbonic acid gas from them during their coagulation, and the consequent formation of a network of minute passages or commencing vessels. Sir E. Home observed this extrication of gas to occur during the coagulation of blood and the inspissation of pus, and he concluded, without experiment, that it also took place in organizable lymph. Sir E. Home has since observed the same kind of hexagonal arrangement, which he supposes to constitute the organization, to occur in the fluid which escapes from the Graafian vesicle of the ovarium. It may be remarked, that the same appearances present themselves during the inspissation of some other organic, as well as inorganic fluids; while, on the other hand, many accurate observers, who have carefully watched the process of the organization of lymph, have never been able to trace the appearance described; from which there seems reason to believe that these are altogether unconnected with any organizing process, and are merely produced by a simple mechanical change.—(See Thomson on Inflammation, p. 214; and some remarks on this subject in Dr Charles Parry's Additional Experiments on the Arteries.)

paratory process of organization, occurs in the parenchyma, and in the parietes of the primitive vessels, before blood passes from the old into the new canal; but more numerous observations than have yet been published will be required to shew whether, after such preparation has taken place, the increase and development of the new vessels formed in the parenchyma, are the consequence of spontaneous motions of the fluid in the vascular space itself, or of extraneous forces, such as the impulsion of the heart or larger arteries.

3. It seems to have been established that new vessels are formed in the adult animal during the state of inflammation, and in certain analogous morbid conditions of the body, by the occurrence of changes in a peculiar fluid separated from the blood, and seldom if ever in the blood that has been extravasated.

4. A great analogy seems to exist in the modes in which new vessels are produced in all the morbid conditions of the body in which organizable lymph is effused; as, for example, in the reunion of divided parts by adhesion or by granulation, and in the junction of entire but inflamed surfaces.

5. During the formation of new vessels in organizable lymph, in the process of direct adhesion or of granulation, it seems probable that vascular spaces and a fluid resembling blood arise in an isolated manner, in the same way as happens in the development of the embryo; and the new vessels, when first produced, have in general the form of loops, which are united with the primitive vessels by a secondary process. The new vessels are sometimes joined with the divided extremities of the capillaries, and at other times with different parts of their entire tubes.

6. The circulation of blood through the cut extremities of a capillary vessel is thus re-established by the intervention of a new substance, and of a new portion of vessel formed in this substance; and this takes place also in the small arteries and veins. The new vessels formed in organizable lymph

are more frequently, however, what may be strictly called capillaries, both as regards their size and their situation relatively to the larger vessels. But it frequently happens that a set of these small new vessels passes from one artery to another, or from one part of an artery to another, and these may be properly denominated arteries, as they convey blood only in one direction, viz. outwards from the heart ; and in like manner, another set frequently passes only between veins, and may be considered as proper veins, as they convey blood only in a retrograde direction.

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In the preceding part of this essay, I have endeavoured to trace some of the principal phenomena which occur during the reunion of wounds of the smaller or capillary vessels, and of the parts which they supply with blood. Appearances somewhat different generally present themselves after any of the Larger Bloodvessels have been cut through.

It appears, from the experiments of Jones, Beclard, Gendrin, and others[1], that *slight* wounds of the larger arteries and veins, which, like all the other organized parts of the body, are themselves copiously supplied with capillary bloodvessels, are healed by a process of organic adhesion very similar to that which has already been described as occurring in other textures; and it may be remarked, that no better examples of adhesion by means of organizable lymph are to be met with than those which occur in the ar-

[1] J. F. D. Jones, Tentam. Physiol. Inaug. de Arteriae Sectæ Consecutionibus. Edinb. 1803. On the Process employed by Nature in suppressing Hemorrhage, &c. London, 1805.—Thomson's Lectures on Inflammation, p. 250, &c.—Weber's Hildebrandts Anatomie, vol. i. p. 252.—Pauli, Comment. Physiol. Chirurg. de Vulneribus sanandis. Gott. 1825.—Gendrin, Hist. Anat. des Inflam. tom. ii.—Beclard, Mém. de la Soc. Méd. d'Emulation. Paris, vol. viii.—Richter, Diss. Inaug. Chirurg. de Vulneratarum Venarum Sanatione. Tubingen, 1812.—Travers on the Wounds and Ligatures of Veins, in his Surgical Essays, p. 216.

terial and venous tissues. But, from the force with which the blood is, in ordinary circumstances, driven into an artery, it is necessary, in order that reunion of the surfaces of a wound in its coats may take place, that the aperture made by the wound should be of a small size, so as not to involve more than a fourth, or at most a third, of the circumference of the arterial tube. In such circumstances the blood still continues to flow through the trunk of the vessel, but a part escapes and coagulates in the neighbouring cellular tissue, preventing the farther flow; shortly after the infliction of the wound, the coats of the vessel in its neighbourhood become inflamed, and organizable lymph is effused, which closes up the aperture, and, by its subsequent inspissation, unites together the divided margins. The organizable lymph is generally poured out in greatest quantity on the inside of the artery; and, in the course of a few days, it becomes so organized as to establish complete reunion. When the wound is longitudinal, it in a short time contracts so much as to be almost imperceptible; but when the wound is transverse, the divided edges generally separate farther from one another, and the space occupied by the lymph is necessarily greater. It seems to follow, indeed, from experiments performed on arteries and veins, that the arterial and venous tissues are reproduced in wounds of the larger vessels, or, in other words, that the lymph, by which wounds in the coats of arteries and veins are united, is soon changed into the proper substance of these vessels.

On the other hand, when the trunk of one of the larger arteries is cut completely through, the flow of blood through it, if not so great as to endanger life, is very speedily arrested; 1st, by the retraction of the two separated ends from one another within their cellular sheath; 2d, by the diminution of its diameter, in consequence of contraction, to a certain extent, of the coats of the artery at its cut extremities; 3d, by the coagulation of blood on the outside and in the

interior of the artery; and, 4th, more especially where laceration has taken place, by the shrivelling and curling up of the internal coats. It appears, however, that the formation of a coagulum of blood within the artery is not necessary to its permanent obliteration, as a coagulum is not generally found when the artery has been tied or cut through, near to a collateral branch in which the blood continues to circulate. Inflammation rapidly succeeds to a wound of an artery, in whatever way its coats have been divided; and a quantity of organizable lymph is effused from the divided coats, generally in the course of four or five hours, which afterwards closes the two ends of the artery by an adhesive process.

It is now well ascertained [1], that when a ligature is tightly applied to an artery, the internal coats are generally ruptured, blood coagulates within the tube, and the divided edges of the ruptured coats adhere together: lymph is effused, as when the whole vessel has been cut, and in about twelve hours, the adhesion between the opposite sides of the artery is so strong as to arrest the flow of blood through it. When the inner coats of an artery have been divided by the application of a single tight ligature which is immediately removed, the vessel remains pervious, and the wound of its inner coats heals speedily and completely. If, however, the inner coats of the vessel be divided in two or more places near each other, by several ligatures, which are immediately removed, or if the inner coats be ruptured by violent elonga-

[1] Petit's Mém. de l'Acad. des Scien. 1731, 35. Desault. Hunter. Cooper.—Jones' Work on Hemorrhage.—Thomson's Lectures, p. 260. —Travers' Observations on the Ligature of Arteries, &c. Medico-Chirurg. Trans. vol. iv. p. 435. Farther observations, vol. vi. p. 632.—Lawrence, A new Method of tying the Arteries. Medico.-Chirurg. Trans. vol. vi. p. 156. Farther Observations on ditto, vol. viii. p. 490.—Crampton on the same subject, vol. vii.—Chas. Bell on the Ligature of Arteries. In Surgical Observations, p. 251.—Experiments on the Poison of Arteries by M. Amussat, Velpeau, &c. Journal Hebdomadaire, &c.—Scarpa, Sull' Aneurisma, &c.—Paper by Béclard in the Mém. de la Soc. Méd. d'Emulat. tom. viii.; and Experiments on the Closure of Arteries by Acupuncture by Mr B. Phillips. Lond. 1832.

tion or tortion of the artery, or by any other kind of external violence, the obliteration of the vessel is brought about by the effusion of lymph filling up its tube, and by the adhesion of its opposite surfaces. Professor Turner[1] has described a very curious but analogous process of obliteration, which sometimes occurs spontaneously in the larger arteries of the living body, as a consequence of the rupture of their internal coats.

On the other hand, if an artery be compressed for a considerable time, without the lesion of its internal coats, or if it be irritated by a foreign body in contact with its external coat, as for instance, by passing a loose ligature round it, or by exposing it to the air, adhesive inflammation is produced in the internal coats, and the obliteration of the canal takes place.

The experimenters already referred to have shewn, that the lymph effused from the incised, ruptured, or irritated coats of arteries forms a sort of plug in the interior of the tube, which adheres firmly round the divided edges so as to obliterate the vessel, and passes gradually into the coagulum of blood, which at first served to stop the circulation through the artery. It appears that lymph is also effused on the outside of the cut or tied artery, from the irritation consequent on the wound or ligature. The coagula of blood in the interior and on the exterior of the artery, which, in some instances, at first assist in arresting the flow of blood, are removed by absorption after the closure of the vessel is effected: the lymph is therefore what forms the permanent and organized obstacle to the escape of blood from a divided, and to its passage through a tied or injured, artery. It is not my intention to enter more minutely into the description of the process by which arteries are closed, but only to mention a few of the circumstances connected with it, which illustrate the present inquiry concerning the organization of lymph and the formation of new vessels.

[1] In the Trans. of the Medico-Chirurg. Society of Edin. vol. iii.

As the closure of the artery proceeds, the organizable lymph adheres more firmly, and over a greater extent, to the internal coat of the vessel; it becomes gradually denser as in other parts of the body, and is penetrated with small blood-vessels, which make their appearance at first in the form of isolated red points and lines, and become more and more apparent, till, in the course of twelve or fourteen days, they are joined into a network, and are connected with the capillary vessels of the coats of the artery, when the lymph appears very vascular [1]. The tube of the artery is at the same time generally diminished in its diameter, as far as the nearest collateral branch through which the blood continues to circulate freely. The plug of organized lymph in the interior contracts, and appears less vascular; and as this contraction increases, the artery becomes quite dense, and assumes the appearance of a ligamentous cord, extending between the two pervious parts of the tube, from which the blood passes into collateral branches.

It occasionally happens, however, that, after an artery has been obstructed by ligature or other kinds of wound, the coats do not contract much or at all at the obstructed portion, and a large coagulum, which becomes filled with vessels, occupies the interior. Several instances of this are mentioned by Hodgson, Seiler, Pecot, Ebel, and others; and Blandin and Lobstein have related two cases which seem to shew that some of the small vessels in the plug of lymph may become considerably enlarged, so as to tend to the formation of a new tube or perforation within the old artery.

M. Blandin [2] relates, that, in examining the body of a man upon whom the operation of ligature of the femoral artery had been performed eight years before death, he found the tube of the artery still nearly of its usual size at the place at which the ligature had been applied, but closed up by

[1] Travers, Med. Chirurg. Trans. vol. iv.

[2] Journal Hebdomadaire de Médecine, tom. vii. p. 199.

a large fibrinous coagulum for a considerable space. This coagulum was penetrated by a tortuous vessel, which came off as a branch from the outside of the pervious part of the femoral artery: this arterial vessel, on passing into the coagulum, divided a little below its middle into two branches, which, separating from one another, went to opposite ends of the coagulum, and each of these branches was again subdivided into smaller and smaller twigs. The appearance of this vessel, which M. Blandin justly regarded as of new formation, was the more peculiar from its having no communication with the neighbouring veins.

The case related by Professor Lobstein[1] is somewhat analogous. A ligature had been applied to the femoral artery two years before death. The articular arteries of the knee were much enlarged; an artery concealed in the interior of the sciatic nerve was nearly of the size of the radial; and branches of the internal and external circumflex formed anastomoses with the articular arteries of the knee. The trunk of the femoral artery was not obliterated or changed into a ligamentous cord, but enclosed a long coagulum, which itself contained an artery of the diameter of the stylo-mastoid. This artery, which was filled with injection, descended in the coagulum for two inches, without giving off any collateral branches. The appearances met with by Blandin and Lobstein would seem to shew, that there existed, in these cases, a tendency to the reopening of the arterial tube, which had been obliterated by organizable lymph; but I am not aware of any case of reunion of the cut extremities, or of the reopening of the tube of an artery, which could be regarded as constituting a complete reproduction of the vessel.

Soon after the obstruction of the tube of a large artery, as is well known, the small branches of the nearest collateral vessels coming from the proximal and distal parts of the obliterated portion, become much dilated, and give passage, by

[1] Traité d'Anatomie Pathologique, tom. i. p. 198.

their inosculations with one another, to nearly as much blood as was originally conveyed through the entire artery. At first the whole of the small branches of the collateral inosculating vessels become generally dilated; but afterwards, some few of these branches become larger than others; the dilated branches increase more and more in size, take a more direct course, and at last a few only are left, which afford a short and easy passage for the blood, from the proximal to the distal part of the obliterated artery[1].

It not unfrequently happens that, after the obliteration of some of the larger arteries, the dilated anastomosing vessels, which establish a communication between its pervious parts, pass very directly between them; so much so, indeed, that were their gradual dilatation and change not traced, it would be difficult to believe that they had been formed from the original small anastomosing capillaries. But in other instances in which the gradual change of anastomosing vessels has not been traced, and in which the communicating vessels have been unusually direct in their course, physiologists have been led to reject the opinion of these communicating vessels being formed by the dilatation of small vessels previously existing, and to believe them to be entirely of new formation. Hence the larger arteries have been supposed, like the capillaries, to possess a power of reproduction, or to be capable of being in some sort regenerated. I purpose to inquire shortly into the grounds for this belief.

When the Carotid artery of animals is obstructed by sec-

[1] See a Dissertation, "Exper. nonnulla circa Vitam Arteriarum, et Circulat. Sanguin. per vasa Collateralia," by F. G. Oppenheim, Mannheim, 1822, in which this subject is illustrated by direct experiments.—Sir A. Cooper's paper in the Med. Chirurg. Trans., vol. iv., and Surgical Lectures, p. 103; also his paper on Ligature of the Aorta in his Surgical Essays, p. 101. Two very fine injected preparations of the leg, in both of which the femoral artery had been tied, in the Museum of the College of Surgeons, Edinburgh, illustrate very well the structure of the enlarged anastomosing vessels, and at the same time shew that no production of any considerable new vessel in the site of the obliterated artery has taken place.

tion or ligature, and more especially when this operation is performed on the arteries of both sides, it has been found that, in addition to a communication established between the proximal and distal parts of the artery through the anastomosing vessels known to exist previously, as has been observed in many of the other large arteries, short vessels very soon make their appearance, which pass more or less directly from the upper to the lower extremity of the carotid above and below its obliterated portion, of which no trace can be discovered in the healthy condition of the parts, and which are consequently supposed to be of entirely new formation.

M. Maunoir, in his Mémoire sur l'Anévrisme[1], records an example of the ligature of the carotid artery of a fox, from which he was induced to regard the regeneration of large arteries as not improbable. The carotid artery had in this animal been tied at two places, and had been divided between the ligatures. The artery itself was obliterated throughout a considerable extent, but a small vessel, about $\frac{1}{2\frac{1}{3}}$th of an inch in diameter, passed from the abrupt rounded end formed by the proximal pervious portion of the carotid below, to the distal pervious part above.

Dr Parry[2] was the first in this country who noticed similar appearances in the obstructed carotid arteries of animals; and he has given at considerable length an account of the experiments on which he founds his opinion, that arteries are endowed with a power of reproduction not known before his discovery. He found, in examining a ram, in which the carotid arteries had been tied nearly a year before, that the place of the obliterated and very much diminished portion of the carotid of one side, where the ligature had been applied, was occupied by five smaller vessels, about an inch

[1] See Jones's Work on Hemorrhage, Note S. p. 202.

[2] Experimental Inquiry concerning the Arterial Pulse. London, 1816. On a farther power of the Arteries, &c. p. 153.

or an inch and a half long, some straight and others tortuous, which passed from the extremity of one pervious part of the artery to the other. Dr Parry [1] adduces the following arguments in favour of the opinion that these communicating vessels were of new formation, and not produced by the dilatation of collateral anastomosing vessels previously existing: 1. That in many dissections of the carotid arteries, he had never been able to find such capillaries; 2d, That, had such vessels existed, they must have been divided by the ligature; 3d, That such anastomosing vessels, which take the form of an arch or bow passing between one part of a large artery and another, are never observed in animals; 4th, That the vasa vasorum, which some imagined might, by their dilatation, give rise to these new communicating vessels, do not come off directly from the tube of the large artery on which they are ramified, but are branches of the vessels going to the surrounding parts; and, 5th, That a considerable quantity of lymph which undergoes the process of organization, is generally effused on the exterior of the artery. These remarks, though insufficient to establish that all the communicating vessels observed must necessarily have been of new formation, seem to shew that some part of them at least must have originated by other ways than the simple dilatation of anastomosing vessels previously existing.

A farther series of experiments on this subject is related by Dr Charles Parry, in his work entitled "Additional Experiments on the Arteries," published in 1819. In the examples of ligature of the carotid artery, followed by a recommunication of the pervious parts, which are related by Dr Charles Parry [2], the arrangement of the communicating vessels is more complicated than in those observed in the first trials; and several of these examples seem very strongly to oppose the opinion, that the new vessels are produced by

[1] P. 169 of his Inquiry.

[2] Experiments, p. 1.—On the Growth of Arteries, p. 15.

the dilatation of previously existing capillaries. Dr Charles Parry relates the results of the application of ligatures to fourteen different carotid arteries. In three sheep, the artery was tied on one side only; in two, it was tied on both sides with a single ligature; and in two others, in which both arteries were tied, a double ligature was applied on one side, and about two inches length of the artery cut out: in all there occurred more or less of what he called the complete renewal or reproduction of the artery, or what may perhaps more correctly be described as the recommunication of its pervious portions by short intervening branches, these being in some instances quite straight and simple, in others very tortuous and complicated in their course.

The results obtained by Dr Charles Parry, as well as the excellent outlines which he has given of the communicating vessels, have done much to illustrate the nature of the peculiar process which occurs after the obliteration of the carotid artery. There is, however, in his work, much want of minute description of the structure of these vessels, and of the parts surrounding them, as well as of an accurate comparison of the appearances observed after the experiments with the natural structure of the parts in the same animals.

Since the appearance of Dr Charles Parry's work, his experiments have been repeated by others with very analogous results. In an Essay on the Regeneration of Arteries,[1] by Professor Mayer of Bonn, published in 1823, similar experiments on rabbits are described. Dr Ebel[2], a Prussian, has described experiments of the same kind on dogs, horses, and sheep, in a dissertation published at Giessen in 1826; and in the Journal des Progrès, &c. for 1828, there

[1] Program. Nat. Frid. Gul. iii. Celeb. Bonnæ, 1823.—See also Wiesemann de Coalitu Partium, &c p. 70, and Weber's Hildebrandt's Anatomie.

[2] De Natura Medicatrice sicubi Arteriæ Vulneratæ et Ligatæ fuerint. Giessæ, 1826.

is an Essay on the Regeneration of Arteries by M. Christiani, in which experiments by Dr Schoenberg of Copenhagen, Professor Foerster, Dr Zuber of Vienna, and by the author himself, are referred to and described.

It seems to be fully established by the experiments just alluded to, that nearly the same appearances uniformly present themselves after the sudden obliteration of the carotid artery; and that the peculiar communicating vessels are found in a sufficient variety of quadrupeds, to warrant the conclusion, that their structure has some relation to a peculiarity of structure in the carotid artery. Most of the authors who have related their experiments on this subject, have held the same opinion as Dr Parry, and have believed that their observations on the carotid artery tended to prove the existence of an independent power of reproduction in arterial tubes of a large size. Many circumstances, indeed, seem to shew, that the communicating vessels formed in the vicinity of the obliterated carotid are partly of new formation.

From the researches of Jones, Travers, Pecot, Ebel, and others, it is well ascertained that lymph is effused in considerable quantity on the exterior of an artery, at the place where its coats have been divided or tied, and frequently also over the outer surface of the vessel, throughout the whole of the space in which it has been separated from the neighbouring parts. The lymph effused on the exterior of the artery varies much in quantity according to the nature of the injury: it sometimes forms a uniform layer on the wounded surfaces, and at others a large tumour, in which the ends of the artery are imbedded. This lymph undergoes the process of organization, and frequently embraces the artery so closely, that it becomes difficult to recognise the ligamentous remains of the obliterated portion of the vessel. Dr Jones mentions several remarkable examples of this. Among others, he relates the result of the examination of a dog, in which, seventy-two hours before death, two ligatures had been ap-

plied to one of the carotid arteries, at about the distance of an inch from one another, and the intervening part of the artery had been cut out. It was found that, extending from the curvature of the aorta, to more than an inch above the extremity of the artery next to the head, there was a considerable layer of coagulable lymph, in which the artery was completely enclosed. The effused lymph extended over the trachea, and over the parts on the other side of the artery. The extremity of the portion of artery next the head was so completely surrounded with coagulable lymph, that it was impossible, from an external view of it, to say exactly where it terminated.[1]

Dr Parry assigns the effusion of lymph on the external surface of the tied carotid as one of his reasons for believing the communicating vessels to be of new formation; but, as the animals on which he experimented were not examined till a period of nearly two years after the operation had been performed, the direct observation of the formation of the vessels in the lymph was not made by him. In the greater number of Dr Charles Parry's experiments also, the animals were examined after a very long interval, so that no good opportunity presented itself of examining the nature of the substance surrounding the wounded artery, in which the communicating vessels must have commenced; but in two animals which were killed soon after the ligature had been applied, he found very interesting appearances, which seem to throw some light on the process under consideration. In one animal, the carotid of one side had been tied with a double ligature, and a portion of the artery two inches long removed from between them. On examination twenty-seven days after the operation, the place of the portion of artery which had been cut out was found occupied by a strong liga-

[1] Jones on Hemorrhage; Examples in the Dog, p. 49: p. 90. pl. viii. figs. 1. and 2.; and p. 147. pl. xiv. fig. 1.; in the Horse, p. 127. pl. xi.; and p. 131. pl. xiii.

mentous body, resembling very much, in its external form, the original artery: it joined the two obliterated ends of the artery together, and was completely incorporated with the external tunics at these places. "One or two small arteries arose" from the end of this ligamentous body, which was, in all probability, the remains of condensed organizable lymph. These vessels took their origin at the side farthest from the heart, "but did not reach the end with which they were ultimately to be united [1]."

In another experiment, Dr Charles Parry found in a ram, both the carotids of which had been tied two months before examination, that one of the arteries, though diminished in capacity, still continued pervious (owing perhaps to the escape of the ligature, or to some other circumstance not ascertained), but the other was quite obliterated for a certain space, and "condensed cellular substance was interposed between the two stumps, and supplied a bed for new arteries, which were now seen connecting the ends of the vessel, and had re-established the circulation." [2] Dr Charles Parry very correctly supposes this condensed cellular substance to be produced from organizable lymph, and the origin of the vessels to be the result of a farther process of organization in the same way as happens in adhesion. This seems, in fact, to be the most correct view of the subject; but at the same time, it does not necessarily follow, as the Drs Parry suppose, that all the communicating vessels are formed in the same way. There seems, on the contrary, every reason to believe, that several processes concur to give origin to them, and that, while in those examples in which large portions of the carotid artery have been enclosed between ligatures or entirely removed, it is impossible to conceive some of the communicating vessels to arise otherwise than by new formation; many circumstances seem to shew that, in other instan-

[1] See farther Experiments, p. 33.

[2] P. 35.

ces, a great many of these vessels are produced by the simple dilatation of anastomosing branches.

It appears from many experiments which have been recorded on this subject, that the peculiar communicating vessels frequently do not make their appearance when only one carotid has been tied or otherwise obstructed. There are, however, considerable varieties in this respect. Several examples are mentioned by authors, in which, after the ligature of the carotid artery, the blood was conveyed from the proximal to the distal pervious parts of this vessel, by the dilatation of known anastomosing branches, exactly as happens in other parts of the body. Dr Jones mentions an instance of this in the dog [1]. After the application of a ligature to the carotid of one side, the anastomosing branches of the superior and inferior thyroid arteries became dilated, and served to convey the blood from the lower to the upper part of the carotid, while no short communicating vessels were seen to pass between the obliterated stumps. Dr Ebel mentions several similar instances, and among others relates the case of a dog, in which both carotids had been obliterated by ligature. In this example he found the natural anastomosing vessels of the superior and inferior thyroid considerably enlarged, so as in some degree to supply the place of the carotid arteries; but he observed at the same time small vascular twigs which passed nearly directly between the ends of the pervious parts of the carotid arteries.

In other instances, again, in which communicating vessels pass nearly directly from the lower to the upper part of the carotid artery, it is easy to see that their origin must be owing to the enlargement of natural anastomosing vessels, because their course is considerably longer than the extent of the wound, or the space usually occupied by the lymph effused in consequence of the operation; and it is by no means difficult to explain how the appearance of a simple arch or bow

[1] Work on Hemorrhage, pl. xv.

of vessel, passing from one part of an arterial trunk to another, is produced. We have many analogous instances of such bows occurring after the obliteration of other arteries of the body, where there is no reason to believe that lymph has been effused so as to give rise to the formation of any considerable new vessels; and where, indeed, the gradual change and dilatation of the very small anastomosing branches which afterwards give rise to the bow, may be observed [1]. The disappearance of the numerous subordinate branches, proceeding from the communicating arch to the neighbouring parts, seems to be a secondary occurrence; it does not appear to take place till a long while after the obliteration of the main artery, and is probably caused by the diminution which these vessels undergo, in consequence of the greater determination of blood through the new and wider channel formed by the communicating arch into the distal part of the arterial trunk. In some of the drawings which Dr Ebel has given, several of these enlarged natural anastomosing vessels are well represented. They are situated considerably to the exterior of the shorter and more direct communicating vessels that passed between the stumps of the obliterated artery, and seem to enclose them. In other examples, the short and curiously twisted communicating vessels, which spring immediately from the lower stump of the obliterated carotid, are joined above with the branches of the superior thyroid artery, so that we may suppose part of them to be of new formation, and part to be dilated branches previously existing. Dr Ebel has also shewn that, in general, small branches proceeding from the communicating vessels pass off from them to the adjoining muscles and other parts.

Some others of Dr Ebel's experiments illustrate more fully the early origin of the communicating vessels. In a horse, in which both carotids had been tied a month before examination, Dr Ebel found the artery on one side com-

[1] Sir A. Cooper's Surgical Lectures, p. 103.

pletely enclosed in a mass of coagulated lymph some inches long. "This lymph presented throughout its substance many red points which seemed to indicate so many new blood-vessels springing up in it." In a horse in which the right carotid had been tied with two ligatures an inch and a half separate, and the intervening portion of artery removed, Dr Ebel found, two months after the operation, "the ends of the artery two inches from one another, and surrounded with much dense lymph with which many small vessels were interwoven. The ends of the artery were obliterated as far as the nearest considerable collateral branches, and adhered so firmly to the lymph that they could only be separated by the knife. Vessels originating from the lower end, and consequently passing through the lymph, proceeded to the neighbouring muscles; they were unusually tortuous and sinuous, and communicated by open mouths with dilated collateral branches coming from the upper end of the carotid."

Dr Schœnberg[1], whose experiments were performed on goats by cutting through the carotids of both sides at intervals of some weeks, and immediately afterwards closing up the external wound, relates that he found, in examining a goat two months after the operation had been performed, the ends of the artery separated to a considerable distance from one another, and immersed in a dark coloured clot. The cellular texture on the outside of this clot was completely filled with a very fine network of vessels, (some of which might obviously give rise by their subsequent dilatation to the arches, of which mention has already been made;) and in the clot itself a tortuous and intricate network of vessels, between the obliterated ends of the artery, was filled with the injection mass, and carefully dissected out; it is obvious that these last (at least the part of them that was enclosed in the lymph) could only be regarded as vessels of new formation. There seems then, to be every reason to believe, that

[1] Journal des Progrès, vol. xii. 1828, p. 70.

in these instances, as well as in many others, a certain portion of the communicating canals was of new formation, as they were imbedded in the lymph; and that these new capillaries, formed in the lymph around the obliterated extremities of the artery, established a communication with the interior, by their union with the cut vessels or with small collateral trunks which probably existed previously, and that on the other side they united themselves with the cut extremities of twigs of the vessels ramifying in the neighbouring parts; that they became gradually dilated as the organization of the lymph proceeded; that their number decreased as a few of them augmented in diameter; and that at last the communicating vessels supposed to constitute the reproduced trunks of the carotid were thus formed.

From the experiments and observations of which a slight sketch has just been given, it appears that when the flow of blood through the carotid artery is obstructed by ligature, section, wound, rupture, pressure, inflammation or other causes, the vessels which subsequently appear and re-establish a communication between the proximal and distal parts of the artery, differ considerably from those that are usually met with, when arteries in other parts of the body have been similarly injured. The distribution of these vessels seems to bear some relation to that of the carotid artery, and may not improbably depend on the very small number and minute size of the collateral anastomosing vessels arising from the straight part of this artery, at which obliteration has generally been produced.

These peculiar communicating vessels have been observed to be formed in the sheep, goat, horse, dog, fox, and rabbit. They appear to be produced more rapidly, and in greater number, in young than in old animals; and they are generally more numerous and complicated when the carotid arteries of both sides have been tied or cut, either simultane-

ously or at successive periods, than when the artery of one side only has been obstructed.

It appears also, that the length and course of the communicating vessels generally bear a relation to the nature of the injury that has been sustained by the carotid artery itself, or by the surrounding parts, and that the space occupied by them generally corresponds very much in size and figure with that which is occupied by the clots of organizable lymph that are effused on the external surface of the injured artery. These vessels sometimes pass in a straight course from one end of the pervious part of the carotid artery to the other; and this seems to be more frequently the case when they are of small size or few in number. More frequently they are very tortuous in their course, vary much in their diameter, and are intricately interwoven and joined with one another. In some instances, they pass from one part of the trunk of the carotid to another; in others, from one end of the carotid artery to the superior thyroid or some of its branches; and in other instances, to smaller collateral vessels distributed to the neighbouring parts: while at the same time the natural inosculating vessels passing between the superior and inferior thyroid, the vertebral, cervical, and other collateral arteries, become considerably dilated.

The following may be stated as the principal reasons for believing that these communicating vessels do not proceed altogether from the enlargement of vessels previously existing, but are in part produced in organizable lymph by a process of new formation. That they are not enlarged anastomosing collateral vessels, appears from the very small number, and in many places the apparently total absence, of such vessels in the natural state of the parts; and that they are not vasa vasorum seems to be shewn by the circumstance, that the vasa vasorum of the coats or sheath of the carotid arteries, like those of the other great vessels of the body, do not in general communicate directly with the tube of the vessel,

but are derived from branches of the neighbouring arteries; and it must also be recollected that the vasa vasorum, whatever their origin, must have been divided at one part of their course by the ligature or section. As direct proofs of the communicating vessels being new productions, may be adduced, 1st, The mode in which lymph is effused around the extremities of the obstructed or divided artery, and the observation of considerable vessels formed during the organization of this lymph; 2d, The circumstance that the ends of the divided or obliterated artery are generally firmly imbedded in this lymph; and, 3d, The general correspondence of the communicating vessels in length and extent with the effused lymph.

From all that has been related, then, it seems most probable, that, in some instances, the communicating vessels are entirely the result of a process of new formation in the organizable lymph, and that they are formed during the organization of the lymph, much in the same way as vessels of smaller dimensions are produced in the cicatrices of wounds during the processes of adhesion or granulation. The new vessels are probably united with the primitive trunk of the carotid, in some instances by means of vessels formed in the plug of organizable lymph that closes up the interior of the injured artery, which, from the cases recorded by Blandin and Lobstein, appear sometimes to reach a considerable size; and in other instances, by their inosculation with some collateral branches which were previously so small, as to be hardly perceptible. Again, it seems not improbable that in some of those instances in which part only of the communicating vessel is produced by a process of new formation in the organizable lymph, it is joined at both its extremities with collateral anastomosing branches, known to exist previous to the obstruction of the carotid, such as the cervical, thyroid, or muscular twigs.

A more varied series of experiments performed on the same

and on different animals, and on other arteries as well as the carotid, in which the structure of the communicating vessels shall be examined at various successive periods, and the changes which they undergo during the progress of their development accurately traced, is still required to render these conclusions more certain: and at the same time it would be desirable to institute a more accurate comparison than has yet been made, between the natural distribution of the vessels, and that which is met with after the obliteration of the principal artery.

Having now mentioned the principal facts with which I have had an opportunity of becoming acquainted, relative to the organization of lymph and the formation of new vessels, I should have wished to bring forward some original experiments on the more doubtful parts of the subject which have been touched upon, but I have not yet had an opportunity of making sufficiently accurate or extensive observations to render them worthy the attention of the College: the length to which this Essay has already extended must also prevent me from proceeding to treat of the farther modification which the lymph and new vessels undergo, in the more perfect reproduction of some of the principal textures of the body.

FINIS.