EXPERIMENTS AND OBSERVATIONS

ON THE

UNION

OF

FRACTURED BONES.

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IN conformity with the plan originally proposed, I should now take up the consideration of the particular circumstances under which new bone is produced in necrosis, together with the structure of the ossific fabric so produced, compared with that of the original bone ; and with a view to this part of the subject I have made the necessary examinations, and collected the illustrations. But upon reflection it appears improper to separate the consideration of the structure of the bone, from that of the other circumstances connected with its formation ; the whole forms a sort of circle, each part being essential to the rest. I shall therefore pass on for the present to the investigation of the means by which union is effected in fracture.

In the prosecution of this inquiry it affords me much pleasure to acknowledge the continued kindness with which Mr. Heaviside has favoured my progress ; neither can I pass over in entire silence the numerous marks of friendship with which I have been honoured by Dr. Hooper, who on this and every other occasion has afforded me the most liberal assistance ; ever happy to forward the progress of scientific inquiry, he has kindly allowed me to avail myself of many valuable and interesting specimens of diseased bones, which form a part of his own exceedingly select, though extensive, collection of preparations in morbid anatomy.

Unfortunately, however, the information to be derived even from the best preparations is of a very limited nature. They demonstrate the exact condition of parts at a certain point of time, but without unfolding the successive steps previously necessary to such condition.

The circumstances connected with fracture so seldom bring life into danger, that opportunities of observing the progress of union in the human subject rarely occur ; and in comparative experiments those animals have been generally selected, in which the successive steps of the process are conducted upon so minute a scale, that unless the investigation were carried on with the assistance of the microscope, it seems to me scarcely possible it should ever lead to any satisfactory result. Upon

this ground only can be explained the diversity of opinion that has existed with relation to the seat and mode of production of the callus, the uniting medium in fracture.

Some anatomical writers of the present day, it is true, have chosen to talk with much more confidence upon this question than ever Mr. Hunter ventured to do ; but upon comparing their assertions with the results of those inquiries I now have the honour to submit to the Society, it may perhaps appear that their opinions are rather ingenious than just. We must not, in reasoning upon the operations of nature, speak with so absolute a tone as to imply our being in complete possession of all her secret walks, many of which are still unknown.

In the following essay it is proposed, first, to detail the successive steps that have led me through the inquiry, pointing out the observations as they occurred ; secondly, to notice the opinions formed by Haller and Hunter upon this subject ; and lastly, to lay before the Society the conclusions drawn from my experiments.

The following experiments were made upon rabbits, selected at about the age of twelve months, the period at which, from their beginning to bear young, they may be considered to have nearly attained their full growth.

I. My first examination took place in a rabbit, the left femur of which had been fractured. The animal was killed, and the limb filled with fine injection upon the third day. On dissection, the extravasated blood was found pretty extensively diffused through the cellular membrane between the muscles, and even beneath the integuments, as well as in the immediate seat of the fracture. It seemed at first that the effused blood had in various points received the injection; but minute examination by the microscope ascertained that the injected vessels were only those scattered over the fine transparent lamina of the ecchymosed cellular membrane.

A considerable space or sac, within which lay the broken ends of the bone, was filled with a coagulum of blood, the consistence of which was peculiar, not having even a uniform appearance. In some points the adhesion of this coagulum to the bone was much stronger than in others; in colour, the internal part was of a florid red, the external surface being as dark as venous blood.

The periosteum in the neighbourhood of the fracture was so completely charged with the effused blood, that the altered state of the membrane, and the close adhesion to the bone of that which was evidently coagulum only, rendered it at some points extremely difficult to say which was, and which was not, periosteum.

The injection had been very successful, but the vermilion could not be detected at any point passing into the coagulated blood, although the abundance of injected arteries proved that the nearer the seat of the injury, the more active was the circulation.

The fractured ends of the bone were found closed up by a small coagulum of blood deposited just within the opening of the medullary cavity.

The bone was now dissected out, divided longitudinally with a saw, and while immersed in water the soft contents of the medullary canal were lightly swept out by means of a fine camel-hair pencil. It was thus ascertained, that the coagulum divided in sawing through the bone was so firmly adherent to the opening of the cylinder, that while the pencil washed out at once the medullary contents, the coagulum remained firm, and could not be detached even by rough brushing. This adhesion did not appear to be the consequence of vessels shooting into the coagulum; for several parts of the large external mass of coagulum were adherent with the same degree of firmness to the fractured ends of the femur, where the bone is not covered by any membrane, and is of too compact a texture to have admitted of much vascular intercourse.

Upon the membrane lining the medullary canal

the small arteries approaching the margin of the coagulum were numerous and brilliant, but I was not able to trace a single injected vessel shooting into the substance of the coagulum.

II. The second examination took place on the fifth day, after fracture. The vascularity of all the coagula, or rather of the membranous expansions containing them, was astonishingly great, particularly in the large coagulum between the broken ends of the femur. At certain points the bright masses of injected vessels had the appearance of pure vermillion extravasated; but on examining them with the microscope, the arteries, although innumerable, were found to be entire, and everywhere perfectly distinct.

The bone was divided longitudinally, and while immersed in clear water, the medullary contents were brushed out, as before; the injected vessels by this means exposed upon the membrane lining the cavity were found to be much more numerous than in the former examination. The small coagula within the openings at the fractured ends of the bone, were surrounded towards the inside by the most numerous plexus of vessels that can be conceived. The appearance of the cavity of the cylinder near the line of attachment of the coagulum was that of pure vermillion, but on inspection in the microscope the vessels were all found entire; neither at this period could I distinctly

say that any of the injected arteries had passed into the coagulum.

The superior extremity of the fractured bone was subsequently macerated and dried, when it was ascertained that where the broken ends of the bone had rode over each other, the vascular excitement in the periosteum had already manifested itself by the commencement of ossific secretion. The appearance was that of a slight roughness upon the surface, not very perceptible to the naked eye, though perfectly distinct when magnified. It was the result of a regularly circumscribed action, and had the appearance of uneven lines of a rough white substance, laid at intervals upon the brownish smooth surface of the original bone.

III. The third examination was on the ninth day ; and in this, as well as in each of the subsequent examinations, the inquiry was conducted with particular care. The appearances observed in the successive stages of the dissections were preserved by sketches made at the moment, with such notes as might best explain the state of the parts. Numerous thin sections were removed, and laid on glasses for the microscope ; the glasses being numbered, and tracings of each section preserved, with notes of the recent texture and relation of every part, and references to the outlines made at the commencement of the dissection.

The subsequent treatment of the macerated and calcined parts was conducted with the same caution; and this patient and close attention proved indispensable, for no other mode could have enabled me to trace with perfect accuracy the nature of any particular appearance, it furnished a clue which might be traced backward or forward through all the curious gradations of advance after the dissection was finished; and I trust the Society will forgive any apparent minuteness of detail, as my principal anxiety is to bring forward nothing fanciful, nor any thing but what I have myself distinctly seen, and which may also be seen by others, either by repeating my experiments, or consulting the annexed illustrations.

In the examination upon the ninth day, the periosteum, which in the former dissections had been found much thickened from effused blood, was now greatly altered. The increased volume of the membrane, indeed, was the same, the section in some parts being one-fourth of an inch in thickness; but the whole of the colouring matter of the blood was gone, the divided membrane displaying a very curious structure. The colour was a transparent pearly hue, rendered beautifully luminous by the refraction of colour from innumerable injected vessels shooting obliquely through from its external surface down towards the bone. In general consistence it cut smooth, and about

the firmness of stiff jelly. In most parts this altered periosteum very nearly resembled cartilage, though softer and more elastic; but in those points where the two broken ends of the bone lay across each other, the membrane had acquired more firmness and opacity, approaching more closely to the nature of true cartilage.

The recent sections of this thickened periosteum examined with the point of a needle under the microscope, could not possibly be distinguished from cartilage. The uniform areolated texture seen by a transmitted light, answered exactly to that of originally formed cartilage, and to that only; and when a part of the section was gently moved by the needle in the microscope, it was observed to possess the same freedom of expansion and contraction as cartilage, only in a much higher degree.

Within the fractured end of the lower part of the bone the coagulum was pale and colourless; neither was there upon its external surface any trace of injected vessels. Finding, however, a little bit of the edge of the cylinder fractured and loose, I gently raised it up, and then perceived that the internal part of the coagulum had not yet lost its red colour. On examination in the microscope, the red part of the coagulum, or that lodged in the cells of the membrane within the

medullary cavity, was found to be abundantly crowded with injected vessels*.

The femur was next dissected out and dried, and one part of it being divided longitudinally and calcined, was prepared for examination by the solar microscope.

In the course of these operations the progress of ossification was rendered apparent. This process externally had advanced into the cartilaginous periosteum, so as to produce at certain points a considerable elevation of surface; and within the mouth of the cylinder the commencement of the same action was manifest, although apparently established upon a somewhat different principle. The external or superficial deposit had taken place into the substance of the altered periosteum, while internally bone was forming within the substance

* In repeating the ninth day examination in another rabbit, the same plenitude of injected vessels upon the ecchymosed membrane lining the medullary cavity, previous to the disappearance of the red globules, and the same almost total absence of injected vessels in the pale external part of the coagulum, were equally obvious.

A part of the femur, however, laid aside to shew the contrast between the recent and dried state of the injected coagulum, exhibited in the microscope the external surface of the coagulum, or at least that of the incipient ossification within it, plentifully supplied with vessels, the fine extremities of which were filled with injection.

of the coagulum closing the opening of the medullary cavity; and from this latter change having commenced in parts where the coagulum was still red, it is fair to infer, that although the removal of the colouring matter of the blood may be expedient, it is by no means essential, to the commencement of ossification. The ossific deposit upon the outside of the cylinder was a light cellular or cancellated structure, very far exceeded, however, in the delicacy of its texture by that produced from the inner margin of the medullary cavity*.

IV. The fourth examination took place upon

* In a most interesting paper lately read to the Royal Society by Sir Everard Home, the great extent and high importance of whose labours in physiology are well known to the professional world, some exceedingly curious circumstances are noticed with regard to the progressive organization of a coagulum of blood. If a drop of blood placed in a watch-glass is observed in the act of coagulating, air is disengaged in minute globules which presently form numerous canals, and these connecting themselves to each other are very soon seen to pervade the whole substance of the coagulum, a change which the author considers the first step to organization. The peculiar appearance of the ossific fibres which I have myself observed formed within the coagulum in the cylindrical cavity of a fractured bone, renders it probable that the new bone is deposited in the tubular spaces, the existence of which has been thus ascertained by Sir E. Home, although the object of my inquiry being limited, the structure of the pure coagulum was not examined with sufficient care to enable me to detect these canals, presuming them to have existed.

the fifteenth day. The ends of the bone had in this and almost every other instance rode over each other, notwithstanding my having tried almost every possible expedient to prevent motion by the application of splints and bandages.

In the present instance, a small rounded tumor, particularly prominent upon the inside of the thigh, had remained in the site of the fracture. On dissection I found a very tense strong membranous cyst, crowded with injected vessels passing into it from the surrounding parts. On puncturing this cyst, some thin fluid blood escaped, and the sac collapsed. The opening being enlarged exposed rather a large cavity, the parietes of which were of a dark colour from effused blood diffused through its cellular texture.

Within this sac lay the lower end of the upper part of the femur, which, although projecting into the cavity of the sac, was covered up to the very margin of the fracture by an exceedingly fine membrane, the vascularity of which was beautiful and brilliant beyond description. The finely injected arteries were also seen passing in every direction over the surface and into the substance of the small coagula deposited in the cellular structure of the sac.

Just behind the sac, the upper end of the lower

part of the bone was found laying obliquely against the superior portion. At this point an extensive line of union was formed. The two parts of the bone were connected together by a pretty firm cartilaginous state of periosteum, within which ossification was advancing rapidly.

The parts of the femur were next removed, and as in the former instances macerated, divided, calcined, and so prepared for the microscope. By these means the appearances were rendered very distinct. The external or superficial deposit had now become a considerable mass of bone; but the most curious appearance was that of the new structure in the opening of the medullary cavity. More than half this space was filled with the most exquisitely delicate cancellated texture, the apparently fibrous arrangement of which was gently inclined inwards to the centre of the cavity*.

V, In the fifth examination, which took place upon the twenty-third day, the parts of the femur were found on dissection united obliquely, but with considerable firmness; although a degree of motion just perceptible might still be produced between the two parts of the bone. The fractured ends of the femur were found covered with a considerable quantity of new bone forming an irregu-

* See Figures 1 and 2.

lar tumor, covered externally with a well-injected membrane, or periosteum. The appearance and texture of this membrane in most points exactly resembled the original periosteum; but in parts where it had not yet entirely laid aside its lately assumed function it was still thickened, soft, opake, and pulpy. In one part in particular, where ossification was advancing rapidly, I met with a circumscribed portion of cartilage, more firm in its consistence than what had been observed in any preceding examination. The opposed surfaces of the new ossification were in most points nearly in contact, and were apparently connected together by a ligamentous or strong membranous medium; the small piece of cartilage, however, attracted the most particular attention. In shape it fitted into a space, so as to exactly make up the general external figure of the bone; in consistence it was the only specimen I had yet seen that exactly resembled originally formed cartilage; and in its structure it was no less interesting; for it was on examination in the microscope discovered to contain mucous cavities lined with vascular membranes, a peculiarity of organization demonstrated in a former paper to belong exclusively to cartilage connected with ossification.

In effecting a separation between the two extremities of the femur, the abovementioned cartilage was divided, and several thin sections of it laid

upon glass were examined. The fourth section reached the surface of ossification, a part of which was brought away with the next slice. All these specimens were examined while recent in the microscope; and that which exhibited the best illustration was selected for a drawing by the solar microscope, affording a demonstration of the occasional existence of membranes capable of being injected within cavities in new-formed cartilage, together with the appearance both of surface and structure of the recently deposited bone*.

The two parts of the femur were dried, divided, calcined, and the sections subsequently reduced to smooth surfaces, to expose the exact appearance of the minute structure.

The section of the upper part of the femur exhibited upon the one side a very extensive and copious deposit of ossific matter, and upon the other the substance of that mass of new bone, the surface of which had been removed with the sections of the cartilage; while upon the inside of the bone the nearly completed work of ossification was seen, as carried on within the coagulum of blood. That part of the substance of the femur also, upon which the new deposit had taken place, exhibited very beautifully the commencement of interstitial absorption, affording in this respect an

* See Fig. 3.

interesting parallel to the same process, lately in the human subject*.

In the present and most of the other examinations, it appeared that the external ossific action in uniting a fracture, does not commence at the nearest point of contact between the two parts of the bone, but on either side near to that point. This circumstance will be clearly perceived by reference to the annexed figures†.

VI. The sixth and last examination took place upon the thirty-second day. Upon removing the soft parts, the bone was found to have been broken in two places; and in both parts the fracture was oblique. One of these had become completely united, with considerable exuberance of callus; the other had formed two broad surfaces of contact, capable of motion, and was in fact an artificial joint. The more particular circumstances of this appearance I have already adverted to in a note attached to my last paper‡.

The projecting parts of the new and of the old structure were covered with an equal, distinct, but scarcely thickened periosteum; not particularly vascular, although many of its smaller arteries

* See Med. Chir. Trans. Vol. VIII. p. 524.

† See Figures 4 and 5.

‡ In the note referred to, for 23rd day read 32nd day.

were found injected. In several points a large artery was traced, passing into the new work, giving force and activity to the recently established circulation.

The united part of the bone was divided with a saw, and when calcined, its minute texture was seen more clearly; but the specimen was with difficulty made to bear the action of the file, the only means adequate to the complete display of its structure. A small part of the piece was, in preparing, unavoidably broken off and lost, but fortunately every feature of importance was still retained. The drawing produced from this specimen by the solar microscope proved extremely interesting. It afforded a striking demonstration of the ease with which nature works, the readiness with which every instrument fulfils its appointed purpose, and the facility with which the various modes of a commencing operation may become one and the same process in her hand. It exhibits the ultimate result of the differently situated appearances of ossification above noticed, within the cartilaginous periosteum, within the ecchymosed texture of the membrane lining the medullary cavity of the bone, and also within the substance of a coagulum of blood. The whole becomes one, and the little peculiarities observed in the early appearances of the various parts of the work being now lost, the general structure exhibits a light, uni-

form, extended fabric, every day increasing in compactness and solidity.

The present specimen also affords a demonstration of a fact which the natural force of Mr. Hunter's genius led him to perceive; and Sir E. Home has kindly referred me to a preparation illustrating the fact in the Hunterian Museum; although Mr. Hunter did not possess the means of proving it in its full extent, by the examination of its minute structure. The circumstance now alluded to, is the occasional preservation of the living principle in detached fragments of bone. In the present instance, a piece of bone so situated is fortunately preserved*, and is seen laying obliquely across where it must have been left completely detached in the

* I say fortunately preserved, because in two other instances of a similar appearance, the operation of the file in passing over the more compact substance of the fragment, loosened it from its connections, and it was lost. The preservation of the present specimen was owing to the following unforeseen accident. In burning the bone, the fire being dull, I chose to urge it by a gentle stream of air from a pair of bellows. The specimen, when cooled, was laid down and fixed as usual, but was found to resist the file almost as perfectly as if vitrified; and it required more than two hours to bring down the surfaces even partially to the same plane. This excessive hardening of the bone had operated of course most completely upon the fine cancellated parts, the solid substance of the original bone having comparatively escaped, the detached portion, consequently, cut like chalk, being held fast by the surrounding light structure.

midst of the blood effused at the time of the fracture. From the obvious change in the figure of some of its longitudinal canals it appears, that subsequent to the injury, the circulation and other functions of the membranes within the canals had been resumed, and healthy action re-established*.

Having now completed the series of comparative examinations, I shall next state what I have observed as to the structure of callus, in the human subject.

An instance of fractured femur, mentioned in my *Observations in Surgery*, furnished a favourable opportunity for inquiry, the history of the case being known†. I therefore removed a section from the bone, capable of demonstrating the structure of the callus, contrasted with that of the cylinder of the femur. This piece, prepared in the usual manner, was examined in the microscope; previous to which it was observed, that the heat in calcination had produced a greater degree of contraction in the new than in the old bone, so that the section of the new bone had become shorter than that of the original cylinder upon which it was deposited.

In the microscope, the obvious contrast between the structure of the new and old bone, evinced by

* See Fig. 6.

† Case 107.

the disposition and figure of the canals pervading each, was so strong as to prevent any uncertainty in defining the line of separation. The appearance of the original longitudinal canals has been already described ; but the irregular cavities within the new deposit, as well as the uncertain figure and direction of the canals of communication, bore no resemblance to them, although in point of number they were sufficiently abundant to keep the whole mass still within the controul of the active agents, as completely as in bones of original formation*.

To determine whether the primary structure of the original bone was as it were accepted, and allowed to stand, in the communication established with the new work, I made a section passing completely through the fractured bone, and selecting a part of the surface of the section where the cylinder of the femur obviously terminated in a surrounding bed of the new deposit, a thin plate was removed, and when prepared, an exact drawing was taken from it by the solar microscope. The annexed figure will afford the best illustration of the exact appearance, exhibiting the contrast between the minute organization of the new, and that of the old bone†.

Such are the circumstances, as far as I have

* See Fig. 7.

† See Fig. 8.

hitherto been enabled to trace them, relating to the process of union in simple fracture; but it is a fact no less curious than interesting, that from the intervention of peculiar circumstances, as in cases of compound fractures, the order of progression is changed, new actions arise, and new appearances result; and the manner in which these changes occur, serves to throw much additional light upon the source from whence these actions originally spring.

In these cases, as in simple fracture, there is a deposit of ossific matter, sometimes in considerable abundance; but this is not the only consequence of the excitement. Absorption of bone takes place, and that to a variable and sometimes very free extent. In fact, the whole series of appearances may be observed verging towards the process established in necrosis, affording a strong indication that the principle determining the nature, and regulating the tendency of every action set up in the animal economy, is no other than the peculiar exigency of the case, the peculiar combination of circumstances rendering any particular change, or series of changes, necessary*.

* These remarks have been principally suggested by some interesting specimens of bone diseased from gunshot wound and fracture, which were sent to Mr. Heaviside from the seat of war, subsequent to the memorable battle of Waterloo, by Mr. Doratt. In one of these cases, several large pieces of bone, one of them five inches in length, were removed from the femur, three months

I shall now proceed to notice the opinion that others have entertained upon this subject.

after it had been fractured by a musket-ball which passed nearly through the limb. The constitution sinking under increased irritation, was the motive for laying open the wound and searching for the fragments of bone. The patient recovered. Upon some part of the external surface of each of these pieces a superficial deposit has taken place, and the examination of these specimens affords abundant proof that the seat of this deposit is in some cases entirely the cellular texture of the periosteum; for the new work and the old bone were evidently separated by the inner lamina of the membrane, the points of attachment between the new and old bone being few in number. Upon the largest piece the superficial deposit is nearly as thin as paper, and at one part a scale, the eighth part of an inch in length, was quite detached from the body of the bone in macerating, although it still remained entire in itself; clearly shewing that its situation must have been within the periosteum. The state of the bone also demonstrates that the inner lamina of the periosteum had not remained inactive beneath the new deposit, but had become towards the old bone a granulated and absorbing surface, which had already removed a sufficient quantity of the substance of the bone to prove the agency, as well as identify the instrument. The extent of the boundary line of absorption, generally speaking, was found to exceed that of the depositing or ossific action. At various points the contents of the longitudinal canals, immediately beneath the external surface of the bone, have manifestly participated in the excitement, and have evidently been at work, aiding the removal of the fractured portions of the bone.

In another of the specimens, all of which are valuable from the particulars of the cases being attached to them, several pieces of the fractured femur, from a patient who died two months after the receipt of the wound, have become fixed to the shaft of the bone by a copious deposit of ossific matter, the seat of which had principally been the periosteum; although in some points it was evident that the new bone had been secreted into
coagula

Haller, in describing this process, says, "Cal-
lus et ipse ossis est imitamentum; gluten nempe
ex ruptis vasculis et fibris ossis fracti, vasisque la-
ceræ medullæ, exsudans, quod sponte consistit,
et in cartilaginem abit, ut etiam ex naturæ ordine,
ex eodem glutine, cartilago formatur. Idem de-
mum ossescit, quando vasa habet satis dilatata, ut
sanguis ruber in eum penetrare, et secum terreum
succum advehere queat. Ea tunc terra in puncta
ossea, quæ rubia rubro colore tingit, effunditur,
quorum singulum abit in nucleum osseum, qui
vasa recipit, et emittit, quoad cartilaginem omnem
eliserit, ut sola natura ossea supersit*;" in which
he mentions the formation of distinct points or
centres of ossification within the newly formed
cartilage. The description is certainly beautiful;
but if in point of accuracy it were no more to be
depended upon than that which follows in the
next page, where he states that, "Omnibus com-
mune est, gelu esse in principio, tunc cartilaginem,
inde in medio anulum oriri, qui primus ossescit,
et qui paulatim excrescens, cum ossea natura,

coagula of blood. One of the pieces of fractured bone I care-
fully divided with a small fine saw, and found that the thickness
of the superficial deposit was on the average one-sixteenth of an
inch, while the extent of the space beneath, occupied by the
inner lamina of the periosteum, was equal to one-eighth of an
inch. The longitudinal canals near the external surface of the
bone were enlarged in this, as well as in the other specimens.

* Vide *Elementa Physiologiæ Corporis Humani*. Tom. VIII.
page 334.

versus epiphyses extenditur, et cedentem sibi naturam cartilagineam denique in crustam tenuem elidit," his testimony alone should be received with some caution, as I have myself disproved the latter of these two positions, in the observations contained in my paper upon the formation of bone, and as with regard to the former, I found no distinct appearances in support of it in the course of my experiments upon fracture*.

* It is rather curious that so eminent a physiologist as Haller certainly was, should not have been aware that the deposition of bone precedes the evolution of cartilage; a mistake which every succeeding anatomist up to the present day seems to have copied from him, as all have alike fallen into it.

The examination upon which I made out this fact, was only partially entered into in my paper on the formation of bone, from a desire to avoid what appeared to be unnecessary detail. The human embryo at the eighth week was not only examined as to the state of ossification in the limbs; but the ribs were cut away from each side with a pair of scissors, and the soft mass of the vertebral column was divided across in the middle, and the upper half placed with its inside, the lower with its outside to a narrow slip of glass, was examined, and then laid to dry. A very exact drawing was taken from this specimen in the solar microscope, exhibiting the minute centres of ossification for the bodies of the vertebræ laid at regular distances from each other, and answering in their comparative sizes to those of the future bones; the dorsal becoming larger towards the lumbar, and these again being quickly reduced to the smallest conceivable point at the apex of the sacrum.

On the posterior part of the spine, the rudiments of the processes that pass laterally from the bodies of the vertebræ to unite in the future spinous processes were laid in pairs, very distinctly formed. It is remarkable that between every two of the ossific points

Mr. Hunter, however, who may be considered to have depended almost exclusively upon what he had himself seen, has given the following account of the union of fractured bone, in his lectures. "The space between the broken surfaces of the bones and the surrounding parts, is at first filled with extravasated blood from the ruptured

points of the vertebral column several elevated lines were apparent, connected with the surface of each ossific nucleus, and evidently of a more firm consistence than the rest of the gelatin, though not materially more opaque. These lines were considered to be the rudiments of the ligamentous texture enveloping the spine, and this opinion was strengthened by the close analogy between this appearance and that already demonstrated upon the first figure of my paper on the formation of bone, where the lines seen are in my mind unquestionably the rudiments of the tendons in the hand, deposited in the soft gelatinous matter.

The appearance of the vertebral fabric was exactly that which would have occurred, if so many particles of bone had been dropt into an even bed of thin warm glue, and allowed to dry. With the exception of the ligamentous appearance already noticed, no part was more elevated, or more firm than another; neither was there the least perceptible variation that could be detected in the microscope as to colour or shadow, either while recent, or when dried. Now it is well known that the above ossific nuclei exhibited within the cartilaginous bodies of the fetal spine, in a subsequent stage of its formation, produces one of the most beautiful preparations in anatomy; and as cartilage must, like all other substances, be allowed to possess its proper physical qualities, it must certainly be admitted that in the above examination of the spine and extremities, the rudiments of ossification were completely apparent in all parts of the body, without the least indication of cartilaginous developement, and consequently that the visible commencement of ossification precedes the formation of cartilage.

vessels. This first coagulates, and then becomes vascular. The ends of the bones are attacked with the adhesive inflammation, in consequence of which a new operation takes place in these parts. This inflammation which takes place, takes place equally in any detached parts called splinters, but such as are still attached to the soft surrounding parts, and to the bone. Such inflammation produces a disposition to interstitial absorption in them, so that these parts of the bone become softer than common, also an absorption of the angles and sharp edges takes place, in which the processes are taken off, and rendered smooth. They also become vascular, so that the parts fall back into their young state again, whenever they have to perform the operations peculiar to youth. I also believe that in most fractures there are some splinters detached, but they are kept alive still, provided they are not deprived of the living principle themselves, nor the surrounding parts deprived of it, and form a part of the callus. What makes me believe this is, that I seldom if ever examine a compound fracture where this does not take place. If I am right in this conjecture, then the union of the splinter is similar to the transplantation of teeth. If the laceration is great, they may increase the quantity of callus in proportion to the distances between the divided surface of the bones. This new formed substance is a nidus for the bone; it becomes more and more vascular, and firmer and firmer, till it becomes

cartilaginous, and while in the soft state it is in many places pressed by the surrounding parts, and often new moulded to the parts, as in fractures of the ribs. The ossific process begins at the original bones themselves, and extends into the callus, though the formation of bone begins in different parts of the callus, similar to epiphyses."

In the above account, Mr. Hunter considers that "the bones are attached with adhesive inflammation," an idea which is very well borne out by the state of the soft parts, and is nearly parallel to that of a late author, who observes that, "*S'il est permis de conjecturer, on peut croire que l'inflammation de l'os fait la condition essentielle de sa réunion, comme de celle de tous les organes**;" but from the observations I have made it would appear, that the state of the bones affords no support to this opinion, at least according to my mode of reasoning upon the subject; for it is demonstrated by the preceding experiments, that there is not the smallest degree of tumor or thickening of the sides of the bone, nor any material alteration in the organization or appearance of the longitudinal canals within the solid structure. Neither can I conceive that Mr. Hunter expressed accurately what he intended, in saying that "the bone becomes softer than common." It may from sub-

* Delpech. *Maladies Chirurgicales*. Tom. I. page 205.

sequent interstitial absorption become less capable of resisting the effects of pressure or violence ; but there is no ground for suspecting that fracture produces any change in the constituent principles, without which change the consistence of bone cannot vary.

Upon the whole, however, Mr. Hunter's account of the union of fracture is more accurate than any I have seen or heard of, and coincides exactly in many essential points with what I have myself ascertained by experiment*.

Having at length completed the account of my observations upon fracture, I shall now lay before the Society the conclusions drawn from the above enquiry, which will close the present paper.

The first effect of fracture is extravasation of blood into the surrounding soft parts, the quantity poured out varying according to the degree of contusion or complication. This blood is principally diffused through the cellular tissue of the periosteum, increasing its thickness after the manner of ecchymosis in the common cellular membrane ; a similar effusion takes place from the ves-

* In two instances I have had an opportunity of observing the circumstances that attend a deficiency of power in the constitution to unite a fractured bone ; but the consideration of these cases, with that of the treatment best adapted for their relief, I shall probably take up upon some future occasion.

vessels within the medullary cavity, and a coagulum is deposited in each of its openings ; there is also extravasated blood deposited between the fractured parts of the bone in larger or smaller quantity, according to circumstances. But although the smaller coagula in the openings of the medullary cavity, and the larger quantity of blood between the ends of the bone, were probably at the first continuous, they are readily distinguished in examination, the former being more tenacious and elastic, the latter retaining the properties of a common coagulum.

The blood effused in fracture suffers various degrees of change, regulated by its situation ; but under all circumstances it forms the medium in which the ossific process is established. It may be observed that the blood soon coagulates, and that subsequently most of the colouring matter disappears, and it is probable that the greater freedom of circulation is the means of effecting these changes earlier and more completely in the blood deposited in the cellular tissue of the periosteum than elsewhere ; although these circumstances do not materially influence the subsequent establishment of ossification.

When the colour disappears from the blood effused into the periosteum, the altered membrane becoming more firm assumes by degrees the characters of cartilage ; and from its appearance under the microscope, as well as from its power of

facilitating ossification, it may be considered as having taken on all the properties of true cartilage.

The mode of progression in the ossific process seems to indicate a degree of caution, as if a principal object was to guard against the possibility of the least disturbance or motion between the parts of the bone, subsequent to the act of union. We see that ossific matter is first deposited upon the surfaces of the bone, near those points where union is to take place; ossific matter is also secreted round the margin and within the medullary cavity of the bone; and the foundation being laid, the whole work advances from either side into the coagulum deposited between the two ends of the fracture, no point shooting forward beyond the rest, until an extended mass of bone is produced from the apposed surfaces; and while the two surfaces of the new work approach each other, the intermediate soft substance, the remains of the coagulum of blood, increases in compactness, as it diminishes in thickness, the seat of the fracture thus acquiring a remarkable degree of firmness previous to the actual accomplishment of ossific union.

The circumstances of the fracture evidently regulate the quantity and seats of the ossific deposit. In the simple transverse fracture with little contusion, where the bone is immediately reduced, and

the limb kept perfectly quiet, the degree of internal laceration will be small, the effusion of blood inconsiderable, and the ultimate deposit of bone moderate in proportion. Ossification, in this case, is established within each orifice of the broken bone, and also round the external margin, extending itself conformable to the freedom of the preceding effusion into the periosteum, to some distance above and below the seat of the fracture.

In oblique fracture, where the bones have suffered more violence at the moment of the accident, and are retained with more difficulty when reduced, the effusion of blood will be greater, and the quantity of ossific matter formed will be also more abundant. The appearances in the present case will be materially different from those observed in the former. In the transverse fracture the ossific matter is deposited equally, presenting a gentle elevation, extended above and below the line of the division. In the oblique fracture, however, the appearances are less uniform. An occasional degree of motion between the parts of the bone being with difficulty restrained, points of irritation are established, dependent on the circumstances of the accident; and while some parts of the cylinder are progressively covered with ossific matter, others are left naked and exposed. But in the oblique, as well as in the transverse fracture, a free secretion of ossific matter takes place within the medullary cavity, because in both cases a well

supported platform must be brought forward from each of the fractured ends of the bone.

Where, however, the fracture is not only oblique, but attended with extensive contusion, or comminution, the broken ends of the bone will generally ride considerably over each other, giving a new turn to every stage of the uniting process. The effusion of blood will be most conspicuous at certain points, at which points the subsequent changes and ultimate deposit of bone will also take the lead; and upon attentively considering the appearances in these cases it will be perceived, that the powers of the constitution seek to compensate the unfavourable state of the parts, by laying a broader foundation for repair, increasing the extent of the sphere of operation as far as may be necessary for the eventual union of the fragments, with the principal parts of the cylinder into a single bone again.

When the fracture is still further compounded by a wound communicating externally, the constitutional powers foiled in the endeavour to complete the process necessary to complete recovery, establish new actions, and while every exertion is made on the one hand to repair the injury by the abundant deposit of ossific matter, a manifest effort takes place on the other, to effect the removal of whatever parts of the bone may have entirely lost their circulation. This removal is at-

tempted either by the internal surface of the periosteum alone, which takes on a granulated and extremely vascular texture, possessing the power of absorption; or by this means, in conjunction with the soft contents of that portion of the bone which may not have suffered an entire suspension of its vital actions, in which case absorption is excited in the nearest longitudinal canals.

As to the composition of bone formed after fracture, from the constant disposition to crack and split off under calcination, where the new bone was external to the old, and from the uniform but great contraction in exposure to heat, where the new-formed bone was at liberty to contract, I have been led to conclude that the newly deposited bone certainly contains a larger proportion of animal matter than the original bone, and it is worthy of remark, that this character was very distinctly observed in callus examined several years subsequent to the date of its production*.

* This circumstance is curious, because it proves that nature adopts two standards for the composition of healthy bone, in the human subject; exhibiting in this respect a parallel to what I some time since (see Vol. VI. page 276.) demonstrated in birds, the bones of which, in their first formation, contain a very remarkable excess of animal matter, which excess I found disappeared upon the completion of growth, when the internal fabric of the bones is re-modelled, for the purpose of establishing the air-cells and cancelli.

EXPLANATION OF THE PLATES.

PLATE III.

Fig. 1. Exhibits the femur of the rabbit on the fifteenth day after fracture; moderately magnified.

- a a.* The superficial deposit, or that formed within the periosteum.
- b.* The fine ossific texture forming within the coagulum, and advancing towards the centre of the opening in the medullary cavity.

Fig. 2. Unfolds more perfectly the extreme delicacy and fibrous appearance of the ossific structure deposited within the coagulum of blood, the image being very considerably magnified.

- a.* The section of the femur.
- b.* Section of the newly formed ossification.
- c.* The surface of the new work.

Fig. 3. Part of a section of new-formed cartilage, shewing its surface, and a partial section of the ossific deposit within it, on the twenty-third day after fracture.

- a a.* The cavities, with the injected vessels and membranes, within the substance of the newly formed cartilage.
- b b.* The surface of the new bone, full of foramina, as partially seen through the substance of the cartilage.
- c.* A section of the ossific structure, with several injected and divided vessels.

PLATE IV.

Fig. 4. Section of the upper part of the femur, examined on the twenty-third day after fracture.

- a.* The broken end of the bone.
- b.* The superficial deposit upon the upper side of the cylinder.
- c.* The corresponding deposit on that part of the bone from which the section of cartilage (*Fig. 3.*) was removed.

Fig. 5. The minute structure of *c.* upon the 4th Figure, unfolded by withdrawing the screen of the solar microscope further from the instrument, throwing at the same time a more intense light upon that particular part of the object.

- a a.* The solid side of the cylinder of the femur, shewing enlargement of the longitudinal canals.

- b.* The exquisitely delicate and minute texture of the new bone, seen very distinctly.

Fig. 6. Displays the ultimate and complete result of the process of union, although a part of the bone was broken off, in calcination.

a a. The two sides of the femur.

b b. The new bone formed within the cartilaginous periosteum, near the seat of the fracture.

c. That part of the ossific fabric formed within the coagulum at the orifice of the medullary cavity.

d. The comparatively large extent of ossific deposit produced in the coagulum between the two ends of the bone.

e. A detached portion of the fractured bone, involved in the coagulated blood, and eventually restored to its circulation and other functions, as proved by the change in the figure of its longitudinal canals, seen upon the section.

The minute texture of the new bone formed at different points has at this period become so uniform, as to have lost the peculiarities of appearance which at first distinguished that within

the medullary cavity from that within the periosteum.

The effect of interstitial absorption is much less apparent upon this specimen, than upon that forming the fifth figure, although the latter was of the earlier date.

PLATE V.

Fig. 7. Exhibits a section of bone half an inch in length, (from the same specimen as *Fig. 8.*) shewing the structure of the original bone, contrasted with that of the new deposit, by which it is surrounded.

- a.* That part of the bone terminating the broken cylinder, in which is seen the usual appearance of the longitudinal canals.
- b.* A considerable cavity between the internal surface of the cylinder, and the substance of the new deposit.
- c c c.* Displays the beautiful variety in the size and distribution of the various canals and cavities in the new structure, within which the vessels, membranes, and medullary secretions were contained.

Fig. 8. Shews the structure of callus from the human subject, three years subsequent to its formation.

- a.* The surface of the newly formed bone.
- b.* The lower part, or that towards the cylinder of the femur, upon which the mass was deposited.
- c c c.* The irregular cavities and canals within the substance of the new bone.
- d d.* Openings by which the membrane covering the bone externally, established its communication with the cavities within the new structure.

Fig. 1.
Ossific deposit in the Periosteum & that
in a Coagulum of Blood.
15th Day.

Fig. 2.
Deposit in Coagulum
considerably Magnified.
15th Day.

Fig. 3.
New Bone & Canals
within New Formed Cartilage.
23^d Day.

Fig. 4.
Advancing Ossification. 23^d Day.
Nat. Size.

Fig. 5.
Ossification in Periosteum. greatly Magnified.
23^d Day.

Fig. 6.
The appearance of Complete Union.
32^d Day.

Nat. Size.

Fig. 7.

Communion of Canals between the Old & New Bone.

Structure of Callus.

J. Howship del.

J. I. Wedgwood sculp.