MICROSCOPIC OBSERVATIONS
ON THE
STRUCTURE OF BONE.

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THE diseases of bones appear to be particularly curious and interesting; for in the diseased as well as in the healthy condition of these parts of our frame, we see nature putting forth all her ingenuity in subjecting to the laws of animation those principles, that being related more immediately to the earths, are less disposed than softer materials to yield to the various operations necessary for the regulation of all living matter. Thus we see bone under various circumstances taken up from one part and laid down in another. Where from accident or disease the soft parts surrounding a bone are so injured that the nutritious artery perishes, a portion of the bone, more or less considerable, dies; and while that part of the cylinder which has lost its vitality is undergoing the process of separation, another process of equal importance is

commenced, the object of which is to prevent the ill consequences that must otherwise ensue from the weakness and deformity of the limb. A new frame-work of ossific matter of a cylindric shape is produced, surrounding the old bone, and connecting itself to its extremities, which still retain their living principle. By this salutary effort of the constitutional powers, a limb is sometimes preserved, and after having sustained the loss of nearly the whole of the bone originally provided for its support, has in this way eventually recovered complete activity and strength.

But notwithstanding we may view with admiration the infinite wisdom with which the animal machine is constituted, it is impossible to contemplate the changes induced by disease, without feeling the want of more information than we yet possess, regarding the healthy structure and economy of these parts; and it has also appeared to me that many questions relating to the constitution of healthy bone can never be determined with certainty, unless we endeavour to ascertain those secret provisions, by the agency of which nature has appointed and regulated its first production and subsequent growth. On these grounds I was induced some time ago to commence my inquiries by some experiments on the formation and growth of bone, which the Society have done me the honour to publish in their Transactions*, and I now propose

* See Vol. VI.

continuing the series of observations, by considering the structure and organization of bone when it has attained its full growth, with a view to determine more accurately the nature and operation of those powers by which the condition of bone is changed when under the influence of disease.

In the former paper I demonstrated several new facts with relation to the structure of bone and cartilage, which appeared to me to possess considerable importance in a physiological point of view. It was there shewn that the generally received opinion as to the first rudiments of the cylindrical bones being formed upon cartilage was erroneous, they being, in fact, deposited as a secretion from the fine vessels of the periosteum; and that cartilage is subsequently formed to hasten the progress of the work, as well as to determine its figure, where it becomes necessary for the ends of the bones to be accurately adapted to each other in the production of moveable joints. One of the purposes of the cartilage of growing bone was stated to be that of affording convenient lodgment to membranous sheaths which lined the cavities of canals, traversing the structure of the cartilage down to the new bone; that these membranous sheaths were capable of circulating the blood very freely (although, as I then suspected, not in vessels*),

* From more recent examinations of these membranes, where the arteries were injected with very fine quicksilver, I no longer entertain a doubt that the opinion I had partly formed at the time

and were evidently secreting surfaces, furnishing a copious supply of a peculiar mucilage. The nature and arrangement of the foramina upon the ossific surface were also pointed out, and by prosecuting the inquiry through the various orders of animals, it was proved that the same beautiful simplicity that is known to pervade most of the operations of nature, extends also in all probability to this; for in every instance there was the same principle manifested, and the same means employed for the accomplishment of the end, wherever bone was to be produced.

Some objections, it is true, have been brought forward against the accuracy of the above experiments; I cannot however but regard those doubts which have been expressed as to the correctness of the microscopic appearances by gentlemen, for whose liberality of sentiment, as well as extensive knowledge in anatomy and physiology, I feel the highest possible degree of respect, as a strong testimony in favour of the originality of my observations. Subsequent to a paper of mine on this subject having been read before the Royal Society, I took some pains to remove these objections; and it was suggested by a

my former paper was written, is well founded; as I am convinced that the blood is diffused through the finely reticulated structure of the membranous sheaths; the texture of which, although it is extremely fine, must possess considerable strength: for in no instance have I ever been able to trace any appearance of rupture or extravasation in these parts, when injected.

friend that the most satisfactory mode would be to get some person, whose habits of constant application to the microscope rendered him competent to the task, to examine my objects in his own way, and to produce his own figure before seeing mine. This was done. I was favoured with an introduction to Mr. Bauer, the extent, the interesting nature, and the success of whose researches with the microscope are well known, and highly appreciated by the scientific world.

He examined most of the specimens, compared them with my drawings, and found them correct. Of one specimen in particular, that seemed most likely to have given an inaccurate figure, he was so obliging as to make a sketch from by his own microscope, with a micrometer, before seeing the drawing I had previously made by the solar microscope, and upon comparing them together, the size and figure of the corresponding parts upon each of the two drawings were found to be accurately the same *.

* The following is an extract of a letter I subsequently received from this gentleman :

“ Kew, January 10, 1815.

“ I acquainted him with your having called on me some weeks ago, and of your having shewn to me several microscopic drawings on anatomical subjects you made from nature, and that by your desire I examined and compared them very minutely with the natural objects they represented, and that I found them in every

To give every possible facility to the confirmation of what has been asserted, I have endeavoured to state the mode in which each specimen was prepared so clearly, that any person disposed to inquiries of this nature, may with very little trouble satisfy himself how far my observations have been correct, by comparing my illustrations with such specimens as he may himself obtain.

With regard to the subject of the present paper, it appeared that examinations into the structure and economy of perfect or full-grown bone should be made from the most heavy and compact portions of bone, where it is found to be most distinct from the soft parts; upon this principle the solid sides of the cylindrical bones have been selected for this inquiry, in preference to the spongy and cancellated extremities. The *medullary cavity* of a cylindrical bone is understood to be the space within the circle formed by a transverse section of the cylinder; which space is more or less occupied by a finely reticulated ossific structure, the interstices of that structure being charged with soft medullary matter, deposited in fine membranous capsules;

every particular *true* and *correct*; and that by your particular request I made a sketch of one of those objects with my own microscope, and according to my usual method, before seeing your drawing of the same object; the result proved completely satisfactory, the sketch I then made corresponding exactly with the drawing you had made a long time ago," &c. &c.

and by the *canals in bone* it is intended to express those fine tubes, principally longitudinal, which pass through the compact and solid structure of the cylinder of the bone ; which canals have numerous lateral communications with the internal or medullary cavity, and also with the external surface of the cylinder. By a *transverse section* of a bone is meant such a one as will expose the section of the medullary cavity, together with those of all the longitudinal canals situated in the solid structure of that part of the cylinder ; but a *longitudinal section* passes through the centre of the bone, dividing it in a plane parallel to the axis of the cylinder, and consequently not only brings into view the longitudinal extent of the canals, but also their occasional communications, internally with the medullary cavity, and externally with the surface of the bone covered by the periosteum.

In the year 1811, I first examined some transverse sections of the humerus, from the human subject, in the compound microscope. In every instance I found numerous small canals of a circular figure passing in a longitudinal direction, but none of them were empty ; the larger canals being thickly incrustated with an opaque whitish coloured matter, which on examination with the point of a needle, as it lay under the microscope, was found to have the consistence of spermaceti, while the smaller canals were apparently filled up with the same substance, the situation of the canal being

distinguishable only by the brighter colour of its contents compared with the other parts of the surface of the bone. The success of these attempts to ascertain the structure of bone was, however, somewhat uncertain, from the mode in which these specimens were necessarily prepared for examination. The cylinder was first divided with a saw, and the section rendered as smooth as possible with a fine file, but in both these operations the bone-dust was to a certain degree apt to work into the orifices of the canals, so as to obscure the characters of the surface. With a view to remedy this inconvenience, the surface of each section was subsequently pared with a very sharp knife, by which means the face of the bone was in many instances rendered much more distinct.

By these examinations it appeared that all the canals in bone are destined to contain medullary secretions, and not merely to transmit vessels, as has been frequently asserted. But although it was pretty manifest that the proportion of medullary matter was considerable, there was yet no appearance by which to form an estimate of the proportionate space allotted to the vessels circulating the blood, compared with that appropriated to the matter secreted into these cavities. With a view to determine this point, a great number of transverse sections were taken from the recent humerus of an ox; and the surfaces of these sections, prepared as above, were examined in succession. Up-

on all of them the divided extremities of numerous blood-vessels were apparent; but this surface had, in most instances, been so disturbed in the preparation, and the colour of the medullary matter was to all appearance so nearly that of the bone itself, as to render the investigation rather difficult. Upon the surface of one section I found a very clear view of several oblique sections of arteries that were seen distinctly taking a certain course, although it was not possible to discern the boundaries of the canals in which they were contained. However, as these vessels were just large enough to be visible to the naked eye, I included them in a figure marked with a graver upon the surface of the bone, in a space of one-eighth of an inch square, and then made an accurate drawing of them by the microscope, distinguishing the more intense points of colour, where I supposed the vessels passed down into the substance of the bone, from those where the colour gradually became faint, which was attributed to the vessels being at those points obliquely divided upon the face of the section. The piece of bone was then removed, it was gradually subjected to the action of a strong clear fire, and calcined, so as completely to remove all the animal matter. The surface of the bone, somewhat disturbed by this process, was again rendered smooth by means of a fine file, without erasing the engraved line. The dust was then brushed out with a camel-hair pencil, and the piece replaced in the microscope. The clear view which was now afforded of

those canals in which the vessels had been before seen, the correspondence between the appearances of the blood-vessels and the direction of the canals, and the small proportion in point of magnitude which the blood-vessels bore to the canals in which they were contained, afforded a contrast as interesting as it was satisfactory.

Continuing the examination of the recent appearances in bone, I did not give up all hope of meeting with some one section more satisfactory than the rest, one where from the face of the piece being more perfectly than common shaved down to a new surface, I might be enabled not only to see the blood-vessels, but also to distinguish the proportional magnitude of the canals, and their medullary contents. In this expectation I was eventually not disappointed; for in one instance, and in one only out of a great number, I obtained a very fine view of the canals with the whole of their contents, and found that whatever was the size of the canal, the diameter of its vessels was in proportion, and bore a very small part in comparison with the medullary secretion with which the canal was filled. I made a drawing from this section, and took particular pains to render it perfectly accurate.

Having proceeded thus far, it seemed desirable to ascertain in the next place, as clearly as possible, the nature, mode of distribution, and communica-

tion of the longitudinal canals. From what I had already seen, it was evident that the characters and arrangement of these cavities were entirely dissimilar to any thing that is met with in the anatomy of soft parts ; but to convey a distinct idea of their form by verbal description seemed impossible, and the making drawings from them by the compound microscope was likely to prove an undertaking both tedious and fatiguing, and in the end unsatisfactory, because the figures having been taken without the aid of a micrometer, must still be in some degree liable to inaccuracy. However, being determined to proceed, I commenced a series of drawings by the compound microscope, to shew the form, course, and communications of the canals. A longitudinal section of bone from the humerus of the human subject was calcined, the surface was prepared in the manner above-mentioned, and a drawing was made on a magnified scale from a square of one-eighth of an inch. In order to trace the further progress of the canals, the surface of the section was then carefully changed, by passing a fine file lightly over it, and subsequently brushing out the dust. A second drawing was then taken, which represented with tolerable accuracy the change that had been produced in the appearance of each canal by the operation of the file, in laying open new communications, and demonstrating various changes in the figure and disposition of these tubes. By perseverance, a considerable number of these successive figures were, in the course of a few weeks,

finished, exhibiting with some degree of accuracy the mode in which the organization of bone is regulated with regard to these canals.

But after all, the accuracy of this series of figures could not be absolutely depended upon, so that in this point of view I had yet done nothing. This experiment nevertheless afforded me the most profitable information. It proved to me clearly that the use of the compound microscope could not be continued without injury to the sight, and that consequently I must either adopt some other mode of proceeding, or give up the inquiry altogether. Revolving these circumstances in my mind, I recollected that when young, I had once, for the same reason, been under the necessity of laying aside the compound microscope, and had then constructed an instrument formed upon the principle of the solar microscope, and although I foresaw that the trouble of making a new one better adapted to my present purpose would be considerable, there seemed to be no alternative, and I therefore set about it. It is unnecessary to state the successive alterations this instrument underwent, by which in the course of two years its power was increased, and the clearness of the image rendered infinitely more perfect than that produced by the same instrument according to its usual construction. It now only remained to devise some mode by which the application of the file might be regulated, with perfect accuracy, so as to act equally upon all parts of the

surface of the piece of bone. For this purpose I adapted two long slips of wood to each other, so that the one might move freely over the other at a certain distance, in the same plane, without being subject to deviation. Near the further extremity of the lower piece was a sliding groove, to receive a little slip of wood, on which the specimen of bone was glued; and to the corresponding surface of the upper piece the file was fixed, so as to be capable of being moved only in a line that was exactly parallel in every respect to the surface of the bone. Having thus made every thing ready, I availed myself of the first season of fine weather to make drawings from a series of sixteen successive longitudinal sections from the human femur, one-eighth of an inch in length; but owing to a defect in the finishing they were spoiled, and consequently laid aside.

From all that had been hitherto observed, it appeared that the canals were more spacious, and the communications more free the nearer they were to the medullary cavity, but that as they approached the external part of the bone, they uniformly became smaller, although perhaps the points of communication were not less numerous externally than internally. With a view to determine how far this observation was correct, I made another series of tracings from successive sections of a portion of the humerus, only beginning from the external surface, so that the first view exhibited those fora-

mina alone, by which the vessels of the periosteum communicated with those within the canals of the bone. Of this piece twelve successive sections were traced; they were, however, much less interesting than the others, because they merely afforded a demonstration that the canals are smaller as they approach the external surface, and larger towards the medullary cavity; they exhibited no communications between one canal and another, but they served on the whole to confirm the observations I had before made. Some examinations and tracings were next made from transverse sections of the humerus, and also of the femur, from the human subject, but they demonstrated little more than merely the circular figure of the openings of the canals.

From the above observations it appeared that the form and arrangement of these canals might be rendered most intelligible by making a regular series of accurate drawings from successive longitudinal sections. But from the manner in which I had found the canals traverse, it was evident that a section of a piece of bone, one-fourth of an inch long, would convey an infinitely more adequate idea of the structure than a piece that was only half the length. To admit, however, of this increase in the size of the specimen, I found it necessary to make an alteration in the instrument by lengthening the adjusting tube containing the magnifying glass, and changing the lens of two inches for one

of four and a half inches focus, and in this way was enabled to insure a perfectly distinct image of any object within the diameter of half an inch. I now prepared a piece of the humerus, and at the first favourable opportunity made a regular series of twenty longitudinal sections, which were very carefully traced in succession, the drawings being afterwards finished at my leisure*.

Upon consideration, the absolute dependence that might be placed upon the accuracy of this series of figures, rendered it desirable and practicable also, to produce upon paper the exact appearance that a cast taken from these canals would have, had it been possible to have filled them with coloured wax, and afterwards removed the surrounding parts by a process similar to corrosion. The mode I adopted was the following: I took the drawing made from the first section, and distinguished the largest canal that was found, together with all the others obviously connected with it, from the rest of the canals by a stain of red colour. I next observed the ramifications of the same canal, as they unfolded themselves upon the second drawing, and marked them in the same way, and so of all the rest. A piece of paper was then placed upon the drawing of the first section, the two pieces were held against the light, and the extreme boun-

* It was found, from an examination of these sections, that the mean diameter of the canals was about the $\frac{1}{200}$ of an inch; but they varied from the $\frac{1}{100}$ to the $\frac{1}{400}$ of an inch.

daries of the figure being first marked with a pencil to adjust the position by, the coloured canals were traced upon the vacant space. The first figure removed, the second was set exactly as the first had been, and the additional extent of the coloured canals carefully marked with the pencil; by continuing this progressive tracing through all the succeeding sections, a complete figure in outline was obtained, which by comparison with the originals was afterwards reduced to correct perspective, and then finished.

Having now stated in detail the observations I have made upon the organization and structure of healthy bone, it only remains to notice some few additional circumstances that have occurred to my notice in the course of these researches.

The very smallest as well as the largest of the canals appear to me to be furnished with a membrane lining its cavity, which membrane conveys the vessels that deposit the medullary contents of these tubes; in the same way that the fine membranous capsules within the general medullary cavity furnish the marrow contained within the bone. The examinations of the cavities of the canals in specimens of calcined bone exhibit so smooth and bright a surface, that there is every reason to believe there must be a membranous lining, although in recent specimens of full grown bone I have never been able to see it. One reason for this, however, may

be, that the circulation of the red blood is more limited in full grown than in young bone ; for in the examination of foetal bones, where the blood-vessels and canals are much larger in proportion, I have been very frequently successful in my endeavours to inject these membranes, passing from the general medullary cavity into the longitudinal canals. But, even in these instances, the colouring matter of the injection would generally pass only to a certain distance, beyond which the recent specimens exhibited the same shining, smooth, membranous surface continued forward through the whole extent of each canal, only it was colourless and transparent.

I have taken considerable pains to ascertain beyond a doubt, that the canals in bone are so much larger than the vessels they contain as to leave the circulation the same freedom that it possesses in the other structures of the body, although from the minuteness of the scale on which it is carried forward in bone, there is more difficulty in proving it here than elsewhere ; but the principal inducement to perseverance was a confidence that my opinion was well founded. It was, indeed, hardly possible to suppose that blood-vessels were provided, having unyielding channels barely large enough to contain them ; since vessels so circumstanced must have been incapable of increased action, and consequently bones could not become inflamed, which we know to be contrary to fact.

Drawn by M. Henshaw.

Engraved by G. Lewis.