OBSERVATIONS
ON THE
GROWTH OF THE LONG BONES,
AND OF
STUMPS.

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THE conflicting statements which have lately appeared with reference to the growth of the limb after excision of the knee, and comments upon my own remarks¹ relative to the same subject, have induced me to make some investigations upon the mode of growth of the long bones, and to examine carefully the cases that have come under my notice, in which the growth of the bones has been modified by accident or disease.

The solid structure of bone does not admit of the expansion requisite for interstitial growth; and it is generally admitted by physiologists that bones are increased in size, like shells, by the addition of osseous matter to the exterior or to certain parts of the interior, where a special provision for that purpose exists. Thus, in the long bones, an increase of thickness is caused by the continual growth and ossifica-

¹ 'Med.-Chir. Trans.,' vol. xli, p. 193.

tion of the blastematous substance beneath the periosteum, and an increase of length is caused by the growth and ossification of the layers of cartilage between the epiphyses and the shaft.

The few remarks which I have to make relate chiefly to the mode of increase of bones in length. This has been shown by the experiments of Hales, Duhamel, Hunter, Stanley, and Flourens, to be effected, almost or altogether, by addition at or near the ends of the bones; and my own observations are quite in accordance with theirs. The addition may take place beneath the articular cartilage, as in the condyle of the lower jaw, the acromial end of the clavicle, the proximal ends of the metacarpal bones of the fingers, and in most of the long bones of reptiles. Where, however, a considerable amount of growth is necessary, and where the end of the bone is required to be firm, an epiphysis is developed, and the elongation of the bone is effected almost entirely by the growth and ossification, on the side next to the shaft, of the layer of cartilage that remains between the epiphysis and the shaft.

The comparative softness of this layer, upon which its growing property mainly depends, renders it weaker and less resisting than the rest of the bone. It is, therefore, always very shallow and very uneven, and is situated near the end of the bone, where the larger area admits of the structure being less dense, and where, from the proximity to the joint, the bone is least liable to be broken. Had it been situated near the middle of either of the long bones, it is obvious that the bone would have been fit neither to bear weight nor to resist the contractile force of the muscles. Its proximity to the end of the bone is *maintained* by the ossification advancing into it almost exclusively on the side which is next to the shaft. In short, the thickness of this cartilaginous layer, and its position, are so regulated as to permit the necessary growth to take place without weakening the connection of the epiphysis with the shaft.

The cartilaginous layer is, moreover, soft and vascular in proportion to the rate of its growth. We find, accordingly, that the extension of the shaft takes place most quickly, and

is most prolonged, at the end where the bone can best bear the weakening consequent on the more rapid changes in the growing matrix ; and that is, usually, the larger end. For instance, the lower end of the femur is larger, and is more favorably circumstanced for bearing weight and resisting muscular force, than the upper end ; and the ossifying processes are much more active, and are longer continued, at the lower end than at the upper. In the tibia, the lower end is at a disadvantage in comparison with the upper, in consequence of its smaller size, the greater weight borne by it, and the violent shocks to which it is exposed, from its closer proximity to the ground ; and there is less growth here than at the upper end.

In the upper limb the conditions are in many respects reversed ; and growth is, consequently, most active at the upper part of the arm and at the lower part of the forearm.

The clavicles are slender ; they carry the upper limbs slung upon them at right angles ; and they have to resist all the forces which tend to approximate the shoulders to the median line. They are, therefore, ossified at an early period in nearly their whole length ; and subsequent growth takes place in them more slowly than in any other of the long bones. The necessity for epiphyses, with soft layers of cartilage between them and the shaft, is thus avoided. For a short period, it is true, when the chest is undergoing its greatest lateral expansion, and when, consequently, a somewhat greater demand is made upon the growth of the clavicles, a shallow epiphysis appears at the sternal end of each ; but it remains separate only for two or three years—from about seventeen to twenty. The sternal end of the clavicle, where this epiphysis appears, and where growth chiefly takes place, is larger than the other end, and a thick fibro-cartilage is interposed between it and the sternum.

In the cylindrical bones of the hand and foot, sufficient length is attained by means of one epiphysial layer of cartilage ; and it may be noted, that in each of these, with the exception of some of the metatarsal bones, the epiphysis is at the larger end.

Most of the projecting processes of the skeleton serve for the attachment of tendons or ligaments ; and, in order to give them sufficient firmness for this purpose, and at the same time to permit of their proper growth, osseous nuclei are developed in them. It should be borne in mind, therefore, that these apophysial nuclei, as well as the epiphysial centres, have relation rather to the requirements of growth, than to a homotypal plan ; and we must be careful not to attach too much importance to them as guides to a homological arrangement.

A difficulty suggests itself with regard to this account of the mode of growth of the long bones. If the addition to their length be made only at the ends of the shafts, and if the amount added at one end of the shaft be greater than at the other, why does not an alteration take place in the relation of the several parts of the bone to one another, as well as in the relation of the surrounding soft parts to the bone ?

My meaning will be understood by reference to the accompanying diagrams. In diagram 1, the opening of the canal

Diagram 1.—Diagram of young bone, with canal for medullary artery traversing the shaft. The transverse lines mark the divisions between the epiphyses and the shaft. The lines *a, b, c, d, e, f, g,* represent equidistant fibres connected with the epiphyses and shaft.

- „ 2.—Diagram of the bone, enlarged, laid over the shaft of the young bone, showing the position which the canal for the medullary artery and the fibres connected with the wall and epiphyses would retain, unless there were some shifting of the periosteum along the surface of the bone.
- „ 3.—Shows the position which the canal and the fibres really occupy in the enlarged bone ; it is relatively the same as in the young bone, and is due to the interstitial growth of the periosteum and its shifting towards the end where the growth is quickest. The line of the canal in the grown bone is seen to be a continuation of that in the young bone.

for the medullary artery is represented as situated one third from the lower end of the bone. If the shaft of the femur be elongated at the ends, and chiefly at the lower end, the orifice of the canal would, in course of time, be found to have changed its relative position, and to be situated, not one third from the lower end, but at the middle of the bone; and a similar change would take place with reference to all the other points of the bone. Yet we know that this is not the case. The position of the various foramina and processes, in relation to the extremities of the several bones, is the same at all periods of life.

Again, in diagram 1, the lines *a, b, c, d, e, f, g*, represent fibres (muscular or any other) passing from different points along the length of a bone; *a*, from the upper epiphysis; *g*, from the lower epiphysis; *b, c, d, e, f*, from equidistant points along the shaft. According to the view given above, when the bone had acquired the size represented in diagram 2, the fibres *b, c, d, e, f*, would remain attached to points corresponding with the position they occupied in diagram 1; a wide interval would exist between *a* and *b*, corresponding with the amount of new bone added at the upper end of the shaft; and a still wider interval would exist between *f* and *g*, corresponding with the greater amount of new bone added at the lower end of the shaft. But we know that this is not the case. We know that the several fibres passing from the bone and all the surrounding soft parts, like the foramina and processes of the bone, retain the same relations to the ends of the bone at all ages.

It is clear that a growth of the periosteum merely over the ends of the shaft, corresponding to the growth of the bone, such as is usually described to take place, will do nothing to maintain the proper relations of the parts. There must be an interstitial growth in the whole length of the periosteum; and this must be attended with a continual shifting or sliding of the periosteum, and of the structures connected with it, along the surface of the bone at both ends, and more especially towards the end at which growth proceeds most quickly. For instance, the portion of the

periosteum, with the fibre *d*, situate at the middle of the shaft, must, in order to retain its position in the growing bone, be continually descending from the level of the position which it had with reference to the already formed bone. The periosteum, with its subjacent blastema, thus elongated by interstitial growth, and shifting upon the old bone, is enabled to cover the newly added bone at the ends of the shaft; and, of the successive layers of new bone formed beneath the periosteum, each is interstitially longer, as well as larger, than its predecessor, and so suffices to cover and thicken the latest additions which have been made at the ends of the shaft. This manner of shifting of the periosteum furnishes the following explanation of the fact, first noticed by Berard,¹ that the canal for the medullary artery always slants, as it passes outwards, towards that epiphysis which remains separate from the shaft to the latest period.

I have already stated, or intimated, that the end of the shaft at which the epiphysis is last united is the end at which growth takes place most quickly. This is shown to have been the case in the humerus, femur, and tibia of a pig, from which the accompanying drawings (Plate V, figs. 1, 2, 3) were taken. The animal had been fed with madder at intervals; but none had been given for a month before it was killed. It will be seen that the amount of bone added, since the discontinuance of the madder, at the upper end of the humerus, at the lower end of the femur, and at the upper end of the tibia—that is, at the end of the shaft in each bone where the epiphysis is last ossified—is twice as great as the amount added at the other end, or more. I have repeated the same experiment in several other instances, with the same result. This observation is also in accordance with what I have been able to glean from the accounts of experiments made by other observers, though I do not find that either of those observers mentions the fact. Indeed,

¹ 'Archives Gén. de Médecine,' vol. vii. Berard attributed the earlier union of one epiphysis to the better supply of blood furnished to it in consequence of the nutritious artery taking that direction.

their experiments were made with reference to other points, and this appears only incidentally. Thus, Hales¹ pierced the leg-bone (probably the tarso-metatarsal bone) of a half-grown chicken through the scaly covering in two places, half an inch apart. In this bone, as in the case of the tibia, the epiphysis at the upper end is the one last united to the shaft. Two months after, the bone had increased an inch by growth, chiefly at the upper end. The remains of the marks were still the same distance (half an inch) apart. Du Hamel² found the chief growth at the upper end, in the leg-bone of a pigeon and in the tibia of a dog. Stanley, experimenting upon the radius and ulna in dogs, found the growth chiefly at the lower ends; and the lower epiphyses of these bones are last united to the shaft. The specimens are preserved in the museum of St. Bartholomew's Hospital. The drawings of the tibiæ of rabbits experimented on by Flourens³ also show that these bones increase in length chiefly at the upper end. It may, therefore, be regarded as established, that the end of a bone at which the epiphysis is last united to the shaft is that at which the growth takes place most quickly. And, in order to maintain the proper relative position of the soft parts, there must, as I have already shown, be a continual shifting, in this direction, of the periosteum covering the greater part of the surface of the shaft. In the case of the femur, for instance, the periosteum of the lower two thirds of the shaft must be shifting downwards during the whole period of growth. This exerts a traction upon the medullary artery, which causes it to slant downwards, in other words, to run obliquely upwards from the periosteum into the bone; and the canal which transmits it through the wall of the shaft in the medullary cavity takes, of course, the same direction. In the tibia, the growth being chiefly at the upper end, and the shifting of the periosteum and the traction of the medullary artery being in this direction, the canal for the

¹ 'Statistical Essays,' vol. i, p. 340.

² 'Mém. de l'Acad. Royale des Sciences,' 1743, p. 138.

³ 'Sur la Formation des Os,' p. 15.

artery slants downwards, that is, away from the epiphysis last ossified, as it enters the shaft. The same view holds good with regard to the humerus, radius, ulna, clavicle, and all the long bones. Hence it appears that the *obliquity* of the canal for the medullary artery is caused by the unequal rate of growth of the two ends of the bone, and that the *direction* of its obliquity is determined according to the end at which the growth proceeds most quickly, that end being invariably the one at which the epiphysis is last ossified to the shaft.

The proper relative *position* of the canal is maintained, simply, by the addition of new bone around its outer end, and by the absorption of bone at its inner end. At first I thought that a gradual shifting of the canal must be effected by absorption of bone along one side—the side on which the greatest growth of the shaft is taking place—and by bony deposition along the other side. The examination, however, of the bones of animals fed with madder does not corroborate that idea; and further consideration has convinced me that there is no necessity for such a process. The diagram (No. 3) proves that the direction of the canal in the young bone may be so regulated that no alteration is required throughout the periods of growth.

Of the nature and mode of action of the laws which regulate the growth of the body, and which determine the amount of growth that is to take place, and the periods in which it is to be effected, we know nothing whatever. We perceive, however, that they are very definite in their operation, and very exact in their results. The proportionate growth at the two ends of a bone is very regular and determinate; and the exactness of the correspondence of the growth of the two sides of the body, provided it be not interfered with by disease, is very remarkable. How rarely does one limb, or any part of a limb, differ in length from the limb of the opposite side! How exact, too, is the relation maintained between the growth of a bone and the growth of the surrounding parts; not only of the parts immediately connected with the bone, but of the parts at a distance, the blood-vessels, the nerves, and the skin; so

exact and so constant that I never heard of an example of failure in it!

In the case of the limbs, each has the amount and period of growth assigned to it, and these are not dependent upon what is taking place in the opposite limb. The one leg will attain its proper length, though the other have been removed or stunted in growth by disease or other causes; and opposite limbs maintain and attain the same length, because the amount and period of growth which is assigned to each of them is the same. But this is not quite so in the case of the different tissues of any part. It may be that in them also a definite amount and period of growth is assigned to each. Still, for the proper carrying out of the processes of growth, they are dependent upon one another. At any rate, we have abundant evidence that the elongation of the soft parts is dependent upon the elongation of the bones. If anything occurs to interrupt the latter, if the epiphysial line of growth be interfered with or destroyed, there is a corresponding interruption to the growth of all the other tissues in the limb; and if anything occurs to increase unduly the growth of a bone, there is a corresponding increase in the growth of the soft parts. Where there are two bones, as in the leg, if the growth of one be interrupted, that of the other is usually interrupted also, but not invariably. Cases illustrative of these points, and of the growth of limbs after excision of joints, I hope to lay before the Society on a future occasion.

Thus it would seem that the growth of the soft parts is regulated by, and dependent on, the growth of the bones; and that the height of a man is mainly determined by the changes that take place in the shallow strata of cartilage connecting the epiphyses and shafts of his several bones.

Possibly this influence of the bones is attributable to the tension which their elongation exerts upon the soft parts. The tension so caused, operating upon all the structures along the limb, may excite and regulate their growth, just as we observe that the slight stretching of the cellular tissue of the skin and some other tissues, consequent on a

tumour forming slowly beneath them, gives rise to an increase in their growth. We must not, however, overlook the evidences of a reciprocal influence of the soft parts, and particularly of the muscles, upon the growth of the bones. This is shown in the relation which the thickness and density of a bone almost invariably bear to the strength and activity of the surrounding muscles; and when the muscles of a limb are inactive in childhood, from paralysis or disease of a joint, the growth of the bones upon which these muscles act, or, it may be, of all the bones throughout the limb, is usually impaired.

I am not acquainted with any fact which shows that an excessive action of muscles is productive of an excessive growth in the bones; on the contrary, we know that the right upper limb is no longer than the left, although it is in so much more frequent use.

It is difficult to estimate the direct effect of a deficiency in the supply of blood or of nervous influence upon the growth of the bones, because, in either case, the deficiency is generally attended with an impairment of muscular action.

ON THE GROWTH OF STUMPS.

An argument against the explanation which I offered,¹ of the fact that the limb often does not grow after excision of the knee, has been based upon the growth of stumps; for it is conceived that in them there is no "arrest in the subsequent growth of the bones."² To this I was unable to reply, having no exact information on the subject, and being unable to obtain any from the records of surgery or from men of experience. The general impression I found

¹ 'Medico-Chirurg. Trans.,' vol. xli, p. 216. "It is most probable that, in the instances in which a want of proper growth has been observed in the limb after recovery from excision, the sections were made through the *shafts*, and the entire epiphyses, with the thin cartilaginous matrix lying between them and the shafts, were removed."

² Pemberton's "Contributions to Clinical Surgery," in 'British Medical Journal,' 1859, p. 961.

to be that a stump keeps pace in its growth with the rest of the body; but there was no proof forthcoming that it does so.

The following measurements of the stumps of persons who have undergone amputation in childhood, and the following results of experiments upon animals, show this impression to be erroneous. They show that the growth of a stump usually is arrested—that is to say, that it does not keep pace with the growth of the other parts of the body—and that it accords with what the preceding remarks on the mode of growth of the bones would lead us to anticipate, inasmuch as the arrest is *most* marked in those instances in which the growth of the bone takes place chiefly at the *lower* end.

The notes of each of the following cases are from my own case-book. Unfortunately, having had no object of this sort in view, I have not been in the habit of stating exactly the point at which the bone was divided in the operation.

1. John F—, æt. 8; amputation in the right thigh, February, 1851, by circular incision, on account of disease in the tibia, involving the upper epiphysis. In December, 1860, the left femur measured eighteen inches; the bone of the stump measured seven inches. Unless, therefore, the bone were divided near its upper third in the amputation, which is not very probable, it has not kept pace in its growth with the other femur.

2. Frederick F—, æt. 13; amputation at middle of left thigh, April, 1854, on account of injury. In August, 1860, the right femur was seventeen and a half inches, the bone of stump five inches; the latter, therefore, is now not one third, instead of being one half, of the length of the former. A circle of the sawn end of the bone came away before the stump healed; but, all allowance being made for this and other sources of error, it is quite clear that the stump has not grown in proportion to the opposite limb.

3. Anne F—, æt. 14 ; amputation, March, 1854, by flap incision, for protracted disease of left knee. August, 1860, the right femur was fifteen and a half inches, the bone of stump six and a half inches. Here, again, unless the amputation were performed near the upper third of the limb, which is not probable, the stump has not grown in proportion to the other limb.

4. Joseph M—, æt. 6 ; amputation, May, 1855, by circular incision, on account of diseased right knee and failing health. August, 1860, the left femur was fourteen and a half inches, the bone of stump seven and a half inches. Stump conical ; the end of bone covered by cicatrix.

5. Charles L—, æt. 10 ; amputation by flap incision, July, 1857, at middle of left thigh, after excision of knee. August, 1860, the right femur measures fifteen inches, the stump seven.

6. Frederick W—, æt. 14 ; amputation, November, 1855, by circular incision, on account of disease of the lower epiphysis of left femur. August, 1860, right femur measured seventeen inches, the bone of stump seven. The stump conical ; cicatrix covering the end of the bone.

7. Harriett F—, æt. 6 ; amputation of diseased right knee, August, 1855, by circular incision. March, 1861, bone of stump measured seven inches, the left femur fourteen and a half.

8. Cornelius T—, æt. 12 ; amputation of diseased knee, May, 1853, by flap incision. March, 1861, bone of stump measured six inches, the left femur seventeen inches.

9. James M—, æt. 15 ; amputation by circular incision, March, 1854, below middle of left forearm, in consequence of an accident. March, 1861, ulna of stump measures five and a half inches, right ulna ten and a half.

On February 10th, 1860, I experimented on four rabbits, three weeks old.

1. Amputation in the right hind limb; femur, which measured one inch and eight lines, divided one quarter from lower end. A needle passed through the bone half a line above the cut end, and another three lines higher up. Skin sewed up over the bone.

The animal did not thrive, but died February 19th. The wound had healed. The end of the bone was covered by a layer of soft, granulation-like structure, which filled up the crevices in its edge, and was connected with the medullary membrane and the periosteum. There was no suppuration.

2. Amputation in the right thigh, which measured two inches, a quarter of an inch from its lower end. A needle passed through the bone half a line above the cut edge. The stump healed quickly. The animal was killed June 20th. There was an abscess at the end of the stump, not connected with the bone. The end of the bone was involved in tough, fibrous tissue. The bone of the stump (fig. 4) measured two inches. Its upper part (the head, trochanters, &c.) is of the same size as that of the other femur (fig. 5). The shaft is preternaturally curved, and rather thick; towards the lower end it is slightly tuberculated. The medullary cavity is large, but closed at the lower end. The needle has disappeared.

The left femur measures three inches and three quarters. That is to say, it has gained one inch and three quarters since the operation, whereas the bone of the stump has gained only half an inch. The latter, therefore, has not, by any means, maintained its due proportion to the former; instead of being three fourths, it is little more than half the length of the other femur.

3. Amputation in the left leg, which measured two inches and a quarter from the lower end. Needle passed through the tibia half a line from the lower end, and a second needle two lines higher up. Stump healed quickly. The rabbit was killed June 20th. The bone of stump (fig. 6) measures two inches and a quarter. The lower end is

uneven, partly in consequence of slight bony deposit around it, and partly in consequence of slight absorption, which has exposed the upper of the two needles in its middle. The ends of the needle are covered by new bone. The lower needle has disappeared. The medullary cavity is large, but closed below by a thin wall of bone.

The right tibia (fig. 7) measures three inches and three quarters. It has, therefore, gained one inch and three quarters, whereas the bone of the stump has gained only three quarters of an inch; instead of being three fourths, it is now three fifths of the length of the other leg-bone.

4. Amputation in right leg, which measured two inches and a quarter, a quarter from lower end. A needle passed through the bone half a line above the cut end, and a second needle three lines higher up.

Stump healed quickly. Animal killed June 20th. Bone of stump (fig. 8) measures two inches and a half. Its lower end is rounded off and slightly thickened and tuberculated. The lower needle is quite at the extremity of the bone, being exposed in the greater part of its length, and nearly set free, by the absorption which has taken place. The upper needle, covered up by bony deposit, is situated at the same distance from the lower needle as when it was inserted. The end of the bone was involved in tough, fibrous tissue, such as usually forms the cicatrix of a stump.

The left tibia (fig. 9) measures four inches. It has, therefore, gained one inch and three quarters, whereas the stump has gained less than an inch, and its proportion to the left tibia is altered nearly as in the preceding instance, viz. from 3 : 4 to 3 : 5.

In each of these specimens the bone of the stump is as thick as the corresponding part of the opposite bone, showing that there has been no deficiency of growth in this respect. But in neither of them has there been any growth at the end of the stump. On the contrary, that part has undergone more or less absorption. All the elongation that has taken place has been at the upper end of the shaft, and it is quite in accordance with the observations above made,

with reference to the relative amount of growth at the two ends of the shaft in the several bones, that the elongation of stumps in the leg, where the more quickly growing epiphysial line is left, has a nearer proportion to that of the opposite limb than it has in the thigh, where the more quickly growing epiphysial line is removed in amputation. Nevertheless this elongation, even in the leg, has fallen short of the proper amount, as is shown by comparing the length of the interval between the tibia and fibula on the two sides.

On July 23d, 1860, I experimented on two pigs nine weeks old.

1. Amputation a little below the middle of the right thigh, which measured four inches and three quarters. The stump healed quickly. The animal killed February 2d, 1861. The bone of stump (fig. 10) measures two inches and eight tenths. The medullary canal is closed below by a layer of hard bone continuous with the wall of the shaft. The lower end is rounded off, except at the posterior part, where a process of bone, about three lines in length, projects downwards from it. It was involved in tough, fibrous tissue, and, thus covered, projected into a bursa-like cavity, lined by tough membrane, with fibrous processes hanging into it.

The left femur (fig. 11) measures six inches and a half. It has, therefore, gained two inches and a quarter, whereas the stump has gained only about half an inch; and the stump, instead of being rather more than half as long as the other thigh, is considerably less than that.

2. Amputation a little below the middle of the right leg, which measured four inches and a quarter. Stump healed quickly. The animal was killed February 2d, 1861. The stump of the tibia (fig. 12) measures two inches and seven tenths. Its lower end was covered with tough, fibrous tissue. The medullary canal is closed by a thin, transverse sheet of bone; and a ring-like process of bone projects from the surrounding wall, two lines below the level of this septum.

The left tibia (fig. 13) measures five inches and a half.

It therefore has gained one inch and a quarter, whereas the bone of the stump has gained only half an inch, and is now rather less, instead of being rather more, than half the length of the other tibia.

These experiments on the pig are confirmatory of the results obtained by the experiments on the rabbit, inasmuch as they show—*first*, that the bone of a stump does not grow in due proportion to the corresponding bone of the opposite limb; and, *secondly*, that the proportion is more nearly maintained in the case of the tibia than in the case of the femur.

They are in accordance also with the observations above given of the stumps of persons who had undergone amputation in childhood; and the general results of my investigations respecting the growth of stumps is quite in accordance with the remarks made in the former part of this paper respecting the growth of bones under ordinary circumstances, and is such as we might, *a priori*, have expected. The bone of a stump is deprived of the epiphysial line of cartilage, or the means of growth, at one end, and it is also partly deprived of that stimulus to growth which is supplied by the natural use of a part. It accordingly does not elongate in proportion to the corresponding bone of the opposite limb.

Yet, it is said, stumps do sometimes grow too much, so as to be troublesome, and even to require the removal of portions of bone some years after the amputation.

Cases of this sort, undoubtedly, occur now and then; but they are so exceptional that we ought not to found any argument upon them, respecting the growth of bones, or even of stumps, under ordinary circumstances. The very fact of the elongating bone becoming troublesome and requiring removal is an evidence that the processes of growth in the stump are not taking place in a regular and orderly manner. For, if they did, the surrounding soft tissues would increase in due proportion, and, by continuing to afford a sufficient covering to the bone, would prevent its being troublesome. In some of these cases the elongation of the bone must be regarded as altogether abnormal,

resulting from some irritation at the end of the stump, and as being due to the same process as that which leads to the formation of exostoses and of those spicules of bone often seen around the end of a stump where there has been pressure against an artificial limb. The projections seen at the end of the pigs' stumps (figs. 10 and 12) appear to be of the same kind.

In other cases, the projection of the bone appears to be due either to a retraction of the soft parts or to the growth in the soft parts not being proportionate to that which takes place in the bone. I have already hinted that the elongation of the soft parts in a limb, under ordinary circumstances, may be due to the traction exerted upon them by the growing bone, that traction being diffused among them by the mode in which they are disposed about the bone. Thus, the lengthening of the humerus distances the radius, ulna, and other components of the forearm from the shoulder, and so exercises a traction upon the various muscles, vessels, nerves, and other soft parts of the arm. But in a stump the narrow end of the growing bone is pressed against the cicatrix. This may be firm enough to resist the pressure, and to communicate the force to the soft structures descending to and connected with it, and may so exert sufficient traction upon them to cause their growth, and to maintain the form of the stump more or less perfect; or it may yield under the pressure, rendering the stump conical, and even allowing the bone to make its way through. This result is most likely to occur in stumps of the arm and the leg, because, in them, the epiphyseal line that remains is the one upon which the growth of the bone chiefly depends, and the cicatrix is, therefore, subjected to greater pressure from the end of the bone than it is in a stump of the thigh or the forearm. It is also most likely to occur after the circular amputation, because this provides a less thick covering to the end of the bone than does either the flap incision or Teale's method.

Agreeing with most preceding observers, that the elongation of a long bone is chiefly caused by growth at the

epiphysial lines, I have endeavoured in this paper to show that the elongation proceeds most quickly, as well as is continued longest, at the end where the epiphysis is last united, which is usually the larger end; this is attended with a shifting of the periosteum towards that end, and so regulates the direction of the canals for the nutritious arteries.

Secondly, that the growth of a stump is not usually proportionate to the rest of the body, and is least so when the more quickly growing end of the bone has been removed.

DESCRIPTION OF PLATE V.

- Fig. 1.—Vertical section of the femur of a pig which had been fed with madder at intervals. The madder had been discontinued for a month before the animal was killed. The growth is seen to have been greatest at the lower end of the shaft.
- „ 2.—Vertical section of the tibia of same pig, showing the growth greatest at the upper end of the shaft.
- „ 3.—Vertical section of the humerus of same pig, showing the growth greatest at the upper end of the shaft.
- „ 4.—Stump of femur from a rabbit.
- „ 5.—Opposite femur of same rabbit.
- „ 6.—Stump of tibia from a rabbit. The position of the needle indicated by transverse line.
- „ 7.—Opposite tibia of same rabbit.
- „ 8.—Stump of tibia from a rabbit. The position of the needles indicated by the lines.
- „ 9.—Opposite tibia from same rabbit.
- „ 10.—Stump of femur from a pig.
- „ 11.—Opposite femur of same pig.
- „ 12.—Stump of tibia from a pig.
- „ 13.—Opposite tibia of same pig.

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 11.

Fig. 10.

Fig. 12.

Fig. 13.

Fig. 4.

Fig. 5.

Fig. 6.

Fig. 7.

Fig. 8.

Fig. 9.