Thesis
for the degree of
M.D

by
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Some notes

on the repair of bone with special reference to transplantation and other artificial aids.

With diagrams and microscopical specimens from transplantation experiments.

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The microscopic specimens & therefore useless not being permanent, have been withdrawn by the Author with the permission of the Librarian.

Scope of the paper

In this paper it is proposed to review the later writings and investigations on the subject of bone repair, with special reference to those dealing with the restoration of bony parts lost through injury or disease; to detail a number of vivisection experiments conducted by the Author, in France, and to describe the microscopic appearances of sections of transplanted bone showing the mode of union of the transplant to the original bone and the changes it has undergone.

Chapters:

The subjects fall naturally into four groups which will be treated in different Chapters. I Introductory - dealing with some of the recent writings on the subject.

II Details of the experiments.

III Description of the sections and

IV Summary of the results.

Chapter I – Introductory

Introduction

I was led to take an interest in the subject of bone repair during the winter of 1889-1890 when I had the opportunity of examining the bone specimens in Prof. George Buchanan's Museum in the Western Infirmary. A number of those specimens shew very strikingly the facility with which new bone is produced in the repair of fractures and necroses.

Comp'd Fract.

The most interesting is a case of compound fracture of the femur [No. I.C.12. in the catalogue] in which the bone is broken in two places and the middle piece lies between, and transversely to, the lower and upper ends of the upper and lower fragments. This displaced portion is completely necrosed but new bone has been

Middle fragment - necrosed - and covered by new bone

Lower end of femur

Upper fragment

new formation uniting the upper and lower fragments —

formed in considerable quantity and so distributed as to form a sheath round the necrosed part and a strong band of union between the upper and lower fragments in such a way that the function of rigidity is restored.

Photo of fract: The accompanying photograph shows the positions of the fragments as seen from within; the internal condyle and lower third of the shaft separated from the upper fragment by the middle necrosed portion and its sheath of new bone, but attached to upper part of the shaft by a column of newbone evidently produced from the upper end of the lower fragment where the column is almost directly continuous with its long axis and is thicker than at its other attachment. The junction of this

Description of Fract: continued.

New bone to the upper fragment takes place on the ~~outer~~ inner side of the latter about two inches from its lower end. The bony sheath of the dead portion is united to the abovementioned column of new bone on its anterior surface and also to the upper fragment at its lower end on the inner surface. This sheath covers the necrosed bone except for about half an inch at its upper and outer extremity, its surface is rough and irregular resembling the surface of a bone thickened by chronic periostitis.

The late owner of that femur had fallen from the rigging of a ship on to the deck, and, there being no Surgeon on board, he was placed in his hammock without any attempt being made at fixation of the limb or dressing of the wound.

When, after some weeks, the ship came into port it was found that the intermediary necrosed portion was projecting through a wound which was suppurating.

Macewen on Transp:

The (1) experiments of Dr Macewen have shewn that "isolated fragments of bone can live even after transplantation" and it seems fair to suppose that the fragment in this case would have lived but for the septic condition of the wound. The most interesting feature however is that, notwithstanding the presence of conditions so adverse to the repair of tissue, this extensive newformation has resulted. The existence of that new bone prompts a query as to its origin and opens up a question that cannot yet be regarded

(1) Annals of Surgery Vol 6. 1887.

definitely solved.

Theories of Causes of new bone formation

Duhamel held that the periosteum alone through the medium of callus, distinguished as provisional and permanent, was to be credited with the power of producing new bone; again Wagner asserted that from the diploë, as well as from the periosteum, callus was formed which became ossified and repaired the breach of continuity between two fragments of a broken bone. Paget, Virchow, Cornil and Billroth have declared that new bone is formed from various substances, such as extravasated blood, serum, medullary tissue &c. In the case in point the disposition of the new bone round the detached fragment would seem to demonstrate that the vitality of the periosteum had not been destroyed but had survived and enclosed the original bone with

its present sheath, but, on the other hand, it can scarcely be believed that the periosteum alone could have produced the column of bone which unites the upper and lower fragments for the new formation does not extend to the inner edges of the upper and of the lower fragment, and, between the two edges can be seen absorption spaces in the old bone. From its position over the medulla and outer half of the broken surface it is more likely that the new growth was due to the activity of the medulla, periosteum of the outer surface and perhaps the hard bone itself. The specimen shews grounds for comparison of the vitality of the different parts. The parts were in the same wound and yet the detached portion of bone is necrosed, but its periosteum has lived and given rise to new bone, though the fragments which still retain their

vascular connexions have lived and produced newbone. The inference seems to be that bone deprived of its vascular supply has less vitality than that which is not so separated, - as was to be expected; - and that the periosteum has more vitality than both since it has lived and produced bone though separated from its direct blood supply. Thus it would seem that the periosteum is the most potent factor in bone production since its vitality is greater than that of the medulla and the hard parts. It is as wonderful as it is difficult of explanation that the newbone is formed in the long axis of the original bone so preserving the original means of transmission of the weight of the body to the forelegs. Two specimens in the Hunterian Museum illustrate this phenomenon very markedly.

One of these is an oblique fracture of the tibia in which there has been rotation and lateral displacement, the two fragments being also at an open angle. The new bone has been formed in the angle so that the long axis is nearly the same as it was before the fracture. The other specimen is a fracture of the upper end of the right femur just below the trochanter; the fracture is oblique and the upper end of the lower fragment is displaced outwards. New bone exists between the fractured ends but there is also an extensive formation of it on the inner aspect filling up the angle so as to render it less acute and restore the axis of the femur to nearly its normal relation to the head.

The fact that in displaced fractures new bone is formed on one side & that the

place which will best restore the function) to the exclusion of another side shows that, though ~~value of~~ the value of the various bone producers may be ascertained, it is a much more difficult matter to explain what forces govern them and select the position of the new formation so that it will best serve the purposes of the organism.

Experimental Work

Turning now to the experimental work we know from the work of Macewen[1] and others that "not only do detached portions of bone deprived of their periosteum live when reimplanted in their position, but such portions are capable of living after transplantation. Parts of deeper layers of bone without periosteal connexion have been transplanted and lived and grown."

Macewen's

[1] [Annals of Surgery vol 6. 1887]

But Dr Macewen does not say whether the transplant used to fill up an abnormal bone cavity takes any active part in the cementing of itself to the pre-existing bone on which it is planted. There are experiments published to show that it does take an actual part in the repair of the breach but the results are open to question.

(1) Nussbaums case related in the Medical Times and Gazette is as follows:-

Nussbaum's

The case was one of fracture of the ulna in which ligamentous union had taken place, the radius was intact. Nussbaum cut down on the seat of fracture and removed the ligamentous portion, then he removed a piece of the shaft at the fractured end two inches long and to half its thickness

1 Medical Times & Gazette 1874 Vol 1 P 44

Russmann's cont'd

and inserted it between the ends of the fragments. The wound healed well and the ulna became rigid. How it is not shewn whether the remaining gap was filled up from the transplant or from the raised surfaces of the original bone from which the graft was taken. It may have been that the graft remained passive and the original bone, having the advantage of undisturbed blood supply plus the mild irritation of the foreign bodies, was stimulated to increased bone production.

Macewen's restoration of humerus

Macewen published a case in the Lancet(1) in which he transplanted chips of tibia, got from a case of genu valgum where he had performed osteotomy, in place of a humerus lost by necrosis. He cut down to what the periosteum was supposed to be and inserted the

(1) Lancet of 1881 vol I p. 875.

chips of bone with the result that a considerable quantity of new bone was produced. As to the question as to the exact origin of the new bone is not definitely solved, though it is assumed that the transplanted chips are the authors, and the mode of production is not described. It was not suggested, though it appears possible, that the periosteum survived the death of the bone and the fact of the transplants being inserted in its vicinity may have roused its latent power of bone production. The great vitality of periosteum is illustrated in the case cited above (p2) and in the Hunterian and other Museums are specimens of necroses of the whole shaft of long bones incased in new bone which could only arise from the periosteum.

research on periosteum

Trubeart records a case in the (1) Medical Press and Record in which he grafted pieces of periosteum to restore the middle third of a clavicle which had been shot away. Fresh transplants were inserted three times a month for two months when two and three quarter inches of bone had been produced. Two years later shortening had taken place to the extent of a quarter of an inch as compared with the other clavicle. The new bone was fractured nine years later and healed easily. The periosteum was from a newly killed dog. This example shews clearly the remarkable vitality of periosteal tissue, for it produced bone after transplantation into an animal of a different species.

(1) Medical Press & Record. 1885 Oct 21 p 382.

'd dislocation.

Doctor Moore gave the history of a case in which he believed that an inch of new bone was produced from the medulla alone!(1) He reduced an old dislocation of the hip, the head of the femur being on the dorsum ilii, by section through the surgical neck and continued extension by means of weights and pulley. Bonny union took place.
Subsequently he found, post mortem, that new bone had been formed between the shaft and the head of the bone to the extent of one inch. He excludes periosteal aid because that structure could not have stretched and therefore gives as his opinion that the new formation was attributable to

(1) (Lancet. July 1. 1882. p 108)

the medulla. It seems equally reasonable to argue that in ordinary fractures the medulla alone repairs the mischief for the periosteum is usually torn at the seat of fracture, the only difference being, that there is a greater amount of intermediary callus in the former case.

Without accepting the dictum of Dr Moore the case is interesting as shewing the great power of repair possessed by living bone in its natural position.

Schüller

Taking advantage of the osteogenic property of periosteum Schüller (1) artificially increases the growth of bone by producing a chronic inflammatory process of moderate intensity.

(1) Berliner Clinische Wochenschrift Jan 14/90

His methods are 1. Production of a constant passive hyperæmia of the part by means of a constricting elastic band round the limb. 2. By placing the patient in such a favourable position as will best facilitate bone growth. 3. Constitutional treatment. 4 By local operations such as the insertion of steel pins. Following on the same lines Mickulicz (1) employed turpentine successfully in cases of pseudarthrosis. He cut through the soft parts and periosteum and inserted turpentine dressings under the latter. The dressings were renewed every two or three days. Ollier with the same object drove in lead nails.

Seydel (2) in a case of fracture of the parietal bone filled up the gap with chips of tibia the periosteum being retained.

(1) Med. Mos. July 6, 90.

(2) Centralblatt für Chirurgie March 23/90

The above quotations show that sections of bone still in possession of their vascular supply are capable of considerable reparative power; that this power is present to a very high degree in the periosteum — perhaps on account of its greater vascularity — and to a much ~~smaller~~ lower degree in the medulla and hard parts. The undecided point seems to be the role of the transplant, and two propositions are submitted.[1] First — that the soft parts of the transplanted bone live and the hard parts become incorporated with the new formed bone (which is credited to the transplant), and secondly — that the transplant acts only as a provisional prop which is ultimately softened, absorbed and got rid of by excretion.

[1] Macewen Transt 1881 vide Lyon.

There is a third proposition which seems possible and which the results of the experiments, about to be narrated, seem to bear out viz:- That the transplant retains its original composition, takes little active part in the production of new bone and exists passively, fixed by the new formed osseous tissue which is mainly the product of the original bone. It is virtually a comparatively nonirritant foreign body—for no foreign body can be absolutely nonirritant—which by its bulk fills up a preexisting cavity, which may have some power of assisting new growth apart from the mechanical irritation of its presence which by its bulk and rigidity hastens recovery by necessitating a less amount of new formation.

Chapter II — Experiments.

In presenting the details of the experiments it should be remarked that every case is put down irrespective of the result. The causes of failure are apparent and may here be prefaced. In the first place those numbered 1·2·3·6 & 8 were attempts to substitute bone, depalatinized, by long boiling, for the piece of bone excised. They were all unsuccessful, it may have been on account of the antiseptic used (Hyd: Perchlor 1-2000), perhaps the difficulty of fixing the limbs was an important factor or again it is open to question whether the impossible was attempted.

Hopkins

Still the results of Hopkins[1] would seem to show that the last supposition is incorrect for he found that sterilized

1 Med News July 13th 01

bone placed in contact with living bone under favourable conditions becomes absorbed and when placed in contact with the periosteum undergoes organization. The other failures were due to ignorance of the effects of chloroform on rabbits and the want of a practical knowledge of the mode of applying apparatus so as to ensure rigidity of the limb, as well as the difficulty of rendering the limb aseptic.

Experiment I.

On the 27th March 1891 a rabbit was chloroformed, the fur of its left hind leg removed and the skin well washed with Carbolic Solution (1-20). An incision was made over the tibia and one inch of its shaft removed and replaced by a similar piece of bone which had been boiled for 8 hours and then kept for 12 hours in Corros: Sublimate Solution (1-1000) till operation time when it was warmed in

a (1–2000) solution. Salol dressings were applied and plaster splints fixed on.

April, 1st

The animal died today, since the operation it has grown much thinner, the dressings contained a small quantity of serous discharge, the skin wound was closed and no trace of suppuration found. The foreign bone was found in good position surrounded by a sheath of fibrinous matter; on gently separating it a quantity of plastic material was found projecting from the original bone to the medulla of the foreign bone, it was of fibrinous appearance and pink in colour. No pus was apparent.

Experiment II

On the second of April 1890 a rabbit was put under the influence of Chloroform and the ~~former~~ operation repeated, except that the bone had been boiled for 1½ hours.

Ap. 7th 1890.

Today the dressings were undone and found to contain a little blood and serous fluid. The position was good and primary union of the skin had taken place. No swelling of the leg nor bagging was found.

Ap 14th 1890.

Today the rabbit died, the foreign bone had so altered in position as to lie at right angles to the original bone. Suppuration had taken place, the pus was thick and of a creamy colour, it had no smell nor had it found exit. The skin wound was united.

Experiment III

April 9th 1890. Today a rabbit was chloroformed and after the usual precautions removed in place of three quarters of an inch of its tibial shaft a similar piece of bone which had been boiled 2 hours. Dressings were applied and splints, then the

limb was bandaged to the body and covered with jaconet.

April 19th 1890

The dressings were undone today the wound is healed and the foreign bone is in good position.

April 26th 890

The dressings on being removed disclosed the end of the implanted bone projecting through the skin which had sloughed; it was lying loose in a small quantity of pus and extracted without difficulty. Dressings were applied May 9th 1890. — The wound is healed and the rabbit is well.

Experiment IV

April 9th 1891

Today a second rabbit was anaesthetized and after the usual precautions an incision was made

over the tibia and 3/4 inch of the shaft removed. In its place the piece removed from the preceding rabbit was inserted, the transplant having, in the interval, lain in a warm 1-2000 solution of Hyd: Perchlor: The wound was sutured and sealed dressings applied.

April 19th 1890

Today the dressings were undone and found to contain a considerable quantity of serous discharge from the lower corner of the wound where a stitch had cut through the skin. The wound was aseptic and the transplant in good position.

April 24th 1890

On removing the dressings today it was found that the skin had sloughed owing to change of position of the transplant which was lying loose. It was removed and the wound dressed.

May 9th 1890 - This rabbits leg is whole.

Experiment V

May 25th 1890

The first rabbet to have been operated on to day died under Chloroform so a piece of its tibia was excised and put into a warm, 1-2000, solution of perchloride of mercury. The bone had been stripped of its periosteum. The second rabbit received the above mentioned fragment in place of the middle third of its humerus; twenty minutes after excision. The usual dressings were applied.

June 7th 1890.

The dressings were undone today, the wound had healed but the transplant had changed position so that its upper end was internal to the lower end of the upper fragment.

June 11th 1890.

The dressings were removed to-day and it was not thought necessary to renew

them. The transplant is firmly fixed and there are no signs of inflammatory disturbance. The animal is in good health and makes use of the leg.

Aug 10th 1890. The rabbit was killed today and the humerus with transplant put into a decalcifying solution.

Experiment VI

June 11th 1890.

Today the left radius of this rabbit was laid bare and a piece of the shaft about one inch in length was removed and placed in a warm corrosive Sublimate Solution (1-2000). In its place a piece of bone, which had been boiled for 24 hours and warmed in the above solution, was inserted. In this case the muscles were stitched together by deep sutures so as to better secure the foreign bone.

June 19th 1890.

Today the wound was found quite healed up, the limb seemed fairly rigid and the animal was in good health. The cicatrix was covered with collodion and the splints reapplied but the limb was not bandaged to the body.

June 23rd 1891

A slight swelling has appeared at the upper end of the incision and on pressure a few drops of thick creamy pus exuded. Dressings were reapplied after washing with Carbolic lotion (1-20).

June 30th 1891

The foreign bone came away through the hole caused by sloughing of the soft parts. There were no manifest signs of absorption.

Experiment VII

June 11th 1890

This operation consisted in replacing the middle third of a rabbits humerus by the piece of bone excised from the previously operated rabbit. The wound was sutured in a similar manner and sulol dressings applied. The bone transplant had been about half an hour in the boarus antiseptic solution.

June 19th 1890

The dressing was removed today for the first time. The wound is entirely healed and it is not thought necessary to renew the dressing. Splint reapplied.

June 30th 1890

This rabbit is well, bonney union has taken place though not without a considerable amount of deformity.

Sept 10th 1890

The rabbit was killed today and its femur excised and the bone & transplant put into a decalcifying solution.

Experiment FIII

July 1st 1890

Today a rabbit had a piece of decalcified bone inserted in place of part of the shaft of its radius. The usual precautions were taken and salol dressings applied.

July 8th 1890.

The dressing became loose four days ago, strips of the bandage being gnawed through by the rabbit; the surgeon reapplied the dressing with the result that the leg is gangrenous.

Experiment IX

July 1st 1890.

The living bone from the previous experiment, after lying in a warm 1-2000 solution of Hyd: Bichlor: for about twenty minutes, was transplanted deeply among the long muscles of the back of this rabbit - sine pericranio. The usual precautions were taken to procure asepsis.

8th July 1890.

The skin is tensed and shows signs of sloughing, no stitch was loosened - no pus exuded.

July 20th 1890.

The skin has sloughed and the transplants is lying in the dressing.

I note - In this case the piece of bone seems to have been too large

Experiment X

August 9th 1890.

This rabbit had about an inch of its left radius replaced by a piece of similar size from the next rabbit, both being under chloroform at the same time. Salol dressing and the usual apparatus were applied.

August 14th.

Great difficulty has been experienced with this rabbit which has undone the dressings on two occasions at night by gnawing the bandages. Suppuration has ensued and failure is the inevitable result.

Experiment XI

August 9th 1890

This operation consisted in the exchange of about an inch of the shaft of the radius for a like piece of the previous rabbit.

August 14th 1890.

As in the previous case this rabbit has a knack of undoing its bandages necessitating a renewal of the dressing twice since the operation. In this however sepsis had not occurred.

August 20th 1890.

Today the leg was dressed again and the transplant was found displaced so that one end projected through the skin. An attempt to withdraw it showed how firmly it was fixed. Dressings were renewed.

Sept 13th 1890.

The animal was chloroformed and an attempt made to cut off the projecting piece of transplant. The bone splintered and spoiled the result.

Experiment XII

October 29th 1890.

This rabbit had a portion of its humerus excised, the periosteum being left and the wound in it stitched. The animal died shortly after the operation.

Experiment XIII

October 29th 1890.

This rabbit had a portion of its humerus excised with periosteum and the bone from the previous one was inserted.

Oct 30th 1890. — The rabbit undid the bandage and another was applied.

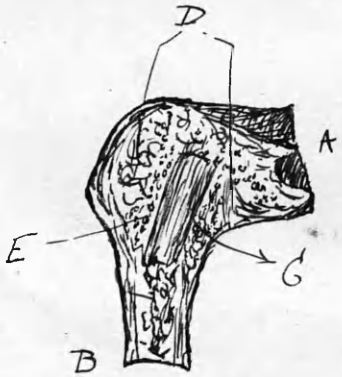
November 10th 1890. — The dressings were renewed. The wound is healed and the position is fair.

November 20th 1890. — The dressing are taken off and not reapplied; bony union has taken place in the same position as at last visit.

Jany 28th 1891. The rabbit was killed today and the bone put into a decalcifying solution.

(1)

Diagram of parts from Experiment V.



A - Upper fragment. D New bone
B - Lower fragment. E Fat-Globules
G - Transplant.

annex

Chapter III – Sections.

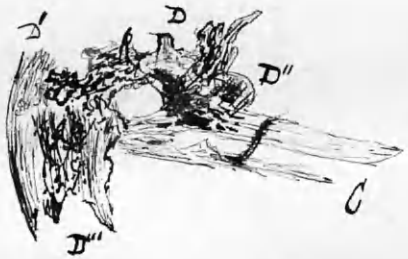
The section from experiment five is numbered 1 and is not stained. For facility of discription two diagrams are given; the first (1) a sketch of a mesial section made before the microscopic sections were cut and shewing the relations of the transplant to the original bone; the second (2) is a drawing of the microscopic section magnified to about two diameters.

The diagram opposite (1) shews that the transplant is imbedded in new bone and connect. tissue, almost in a line with the upper end of the lower fragment but at right angles to the lower end of the upper fragment of the original bone.

On microscopic examination of the upper portion of the transplant in the direction from C to D (fig 2) there are seen absorption spaces of various sizes, increasing in direct proportion of their distance from the hard bone.

(2)

Section from Expt. V. (X2)
Shewing the general disposition of parts.

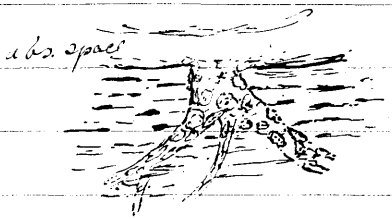


C The transplant E fat globules and fibrous tissue
D New bone

annexed

Between D" and D are two lines of fibrous tissue separating a layer of hard bone on the side of the transplant from the spongey new formation produced by the lower end of the upper fragment, at the D end of this line the structure of the new formation is cartelaginous and contains large absorption spaces numbers of which contain fat globules. The convex margin between D' and D''' is the outer limit of new formation between which and the end of the transplant the bone is arranged in layers parallel to the outer border and almost at right angles to the transplant. The disposition of these layers is the same as the long axes of the lacunae and the difference between their arrangement and that of the spaces in the transplant seems to indicate a different origin - i.e. from the ends of the original bone. With the high power the unimpaired structure of the main part of

the transplant is apparent and the contents of the Howships lacunae are well seen. In some places the connection between the spaces and communicating Haversian systems are demonstrated



The principal points however are:—

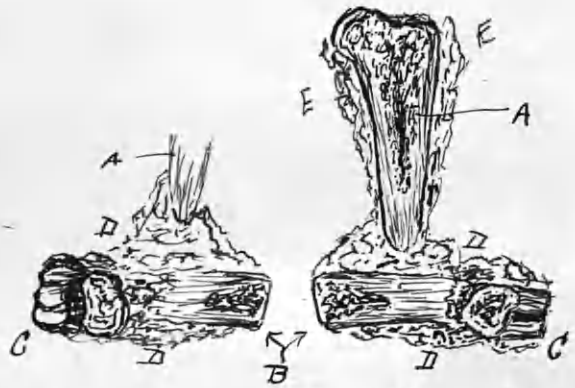
α. The persistence of the greater part of the transplant in its original state.

β. The comparatively small part of new bone formed from the transplant.

γ. The relatively large amount of new bone developed from the original bone.

3.

Diagram of the parts from Experiment No VII



A – upper part of original bone lying in correct position.

B – Transplant lying at right angles to the upper part of original bone (A)

C – lower end of original bone also at right angles to the upper part but not in the same plane as the transplant

D – New bone cementing the fragments

E – Soft parts adherent to upper fragment.

The microscopic sections are of the lower fragment and transplant, the upper fragment being cut off

Sections ii and iii from Experiment VII

Diagram 3 is a sketch of the cut surface of a mesial section and shows the transplant lying between the two ends of the original bone, in a line with but not in the same plane as the lower fragment and at right angles to the upper fragment. Before cutting the sections for the microscope the upper fragment of original bone was removed.

The sections numbered ii and iii are from this experiment, and diagram 4 is a drawing of section two enlarged to twice its size.

The microscope shows that the transplant contains absorption spaces only at the upper extremity and of small size. This end of the transplant is surrounded by fibrous tissue and the sides have a slight covering of connective tissue.

4

Section from Expl: Fij
(x 2).
Shewing the general disposition of parts

B - Transplant
C - Original bone
D New Bone
E fibrous Tissue

anm del

The original bone (C) where it is in contact with the fibrous tissue binding it to the transplant shows evidences of transformation, containing numerous absorption spaces in some of which are fat globules (F).
The high power shows that the surrounding fibrous tissue is in intimate connection with the transplant at the upper end.
Some of the absorption spaces are surrounded by a granular fibrous formation, the intermediary area between the bone and fibrous tissue. A similar union is evident at the original bone where the intermediary layer is larger and contains large cells.
The lacunae near the original bone are larger and contain more cells of the large irregular, granular type.
The noteworthy features are similar to those of the previous specimen and show the greater reparative activity of the original bone.

5

Experiment 13.

Sketch showing the general arrangement of parts of Section

A – Original bone
B – Transplant
C – Ext and lower end of original bone.
E Fibrous Tissue.
D – Upper end of transplant showing absorption & growth also formation of a false joint.

AMM CG

Sections IV and V from Experiment XIII

This experiment has resulted in the fixation of the upperend of the transplant to the lower end of the upper fragment of original bone, not quite at the extremity, and the bony union has been preceded by the formation of a false joint.

Diagram five is an enlargement of the Specimen (V) and will be used as a guide to the description

The original bone is much excavated and in some places new bone is being deposited in concentric laminae filling up the absorption spaces and indentations by layers parallel to the surfaces. Between C and D are seen rods of bone extending from the transplant to the original bone. The structure of these laminae is irregular and various lacunae are seen with both

layers of recent deposition. These columns are evidently newly formed and seem to proceed from the original bone, for, at some parts they are continuous with bands of fibrous tissue on the side of the transplant. Observing next the transplant (T5) it will be seen that the upper extremity appears to take part in the formation of a joint. The end is rounded and covered by a layer of cartilage, whose corpuscles are arranged as in articular cartilage; it is excavated in such a way that the remaining columns of bone are perpendicular to the surface, the lacunae show evidences of considerable new formation at their margins while their centres are occupied by fat. The difference between the old and newborn is well demonstrated, the former having stained more deeply. No synovial membrane can be discovered.

The joint cavity is a new formation and

is also lined with cartilage which however is imperfect at that part where the end of the transplant is nearest the original bone, a similar deficiency is observable in the cartilage of the transplant at this point. The transplant at the place above-mentioned is separated from the original bone by fibrous tissue the greater part of which is undergoing ossification.

At the edge of the cavity the cartilage becomes mixed with fibrous tissue, ~~and~~ is attached to the transplant and of a granular appearance.

The appearances seem to indicate great production of new bone from the old or "original" bone so as to fix the transplant and it will be seen that the neoformations due to the transplant occur mostly within itself.

Chapter IV – Conclusion.

In the foregoing pages it has been the object of the writer to show the great power of reproduction possessed by bone, whose vascular supply has not been diminished or cut off; and more especially to testify, by means of cases and citations, to the remarkable degree to which this process is present in the periosteum. This with the further object of strengthening the proposition set forth at the end of the first chapter as to the changes which occur after transplantation of living bone. The details of the experiments are recorded in the second chapter as briefly as possible and descriptions of the sections are given in the third section.

It will be evident from an examination of the specimens that

the transplants have undergone much less change than the ends of the original bones, that they have been less active in the production of new bone and that, except in the last case, the changes in the transplants are confined to a small portion of the ends next the original bone. Besides assisting in the solution of the question as to the ultimate end of the transplants the results of the experiments may, I think, be taken as supporting the operation of transplantation of living bone in preference to those of insertion of decalcified bone, which becomes absorbed, and other half measures such as the elbow operation of transplanting one end of a bone and keeping the animal in a painfully disagreeable position till union is completed before the operation

is concluded. The operation is not difficult, and the period of recovery ought to be less than when no attempt is made to assist in the filling up of bone cavities. If generally adopted Surgeons would probably be more thorough in their operations for the removal of necrosed bone and less chary of breaking through the new formations to get at the sequestra.

The fact that the experiments were transplantations of bone from one rabbit to another limits the scope of the conclusions to transplants of human bone in the human subject. That this should be the most favourable method appears - in absence of proof to the contrary - to be most probable and the material is at hand in hospitals where amputations are of frequent occurrence.

It may be remarked in closing that

the sections were made three months after the operations and it is possible that the foreign bone, when it has a better vascular supply, may take a more active part in the neoformation if the necessary amount has not already been produced. It would be interesting to know, the condition of the transplant six months or a year after the operation, its liability to fracture and the process of repair of such a fracture. Another point of interest would be its behaviour when the patient became affected by constitutional disease, whether as sometimes happens in cases of simple fracture the callus would degenerate and soften, or, if the blood supply of the limb were impaired, whether the transplant would suffer most and to what end.