IV. "Observations concerning Transplantation of Bone. Illustrated by a Case of Inter-human Osseous Transplantation, whereby over two-thirds of the Shaft of a Humerus was restored." By W. Macewen, M.D. Communicated by Professor Huxley, Sec. R.S. Received May 3, 1881.

Facts previously recorded regarding Transplantation of Bone.

Facts relating to attempted osseous transplantations are few, the details concerning them are meagre, and the deductions drawn therefrom have been received with dubiety.

Re-implanted Portions of Bone.—First there are statements to the effect that portions of the skull elevated by the trephine having been replaced shortly after their removal have become again incorporated with and formed integral parts of the osseous walls. Other observers* construe these facts differently. They say that the re-implanted portions of bone have become absorbed, and that they have been replaced by deposits of fresh osseous matter. On the side of the former Flourens adds the weight of his testimony, believing that he has demonstrated† the vitality of the re-implanted portions of bone in the skull of a guinea-pig.

Periosteal Transplantation in Lower Animals.—Ollier has systematically endeavoured to transplant periosteum, and though in one instance he has demonstrated the possibility of successfully transplanting periosteum, and producing permanent bone-growth therefrom, yet most of the grafts either failed at once or having produced certain osseous spicules were then slowly absorbed.‡

Osseous Transplants in Lower Animals.—Osseous transplants were also tried by Ollier, who convinced himself of the success of grafts placed under the skin, and in regions to which ossification was

* C'est là du moins la réflexion que fait Wagner sur les faits de Merrem, Wiessmann, Walther, Klencke, Heine, qui lui paraissaient incertains.—"Régénération des Os," par Ollier, vol. i, p. 420.

† Flourens gives the above and other somewhat similar facts in the "Comptes Rendus" de l'Institut, Août 8, 1859.

‡ " . . . Nous avons pu constater au bout de trois ans, sur un lapin, la persistance d'un anneau osseux que nous avions formé autour des muscles profondes de la jambe en transplantant un lambeau de périoste pris sur la jambe du côté opposé." —Ollier, *loc. cit.*, vol. i, p. 413.

"Nous avons vu souvent chez le lapin, le chien, le chat et d'autres animaux, des lambeaux périostiques ou médullaires se durcir d'abord, prendre même une consistence osseuse, et se resorber ensuite peu à peu. En examinant alors le lieu de la transplantation au bout de trois ou quatre mois, on ne trouvait plus rien, ou bien seulement au petit noyau fibreux en voie de disparaître."—Ollier, *loc. cit.*, vol. i, p. 412.

foreign.* He judged of the vitality of the osseous grafts by their vascularity, and more especially by the formation of new osseous layers on their periphery. In a rabbit eight months old, he exchanged pieces of the radial diaphysis, transplanting to the left a portion taken from the right, and *vice versâ*. The result was immediate and perfect union in the right radius; in the left suppuration set in and the bone wasted, leaving the periosteum adherent and ossifying.† Wolf, of Berlin, repeated Ollier's experiments,‡ and believed that Ollier had arrived at wrong conclusions, as he (Wolf) had not been able to establish increase of osseous growth in any of his transplants. Ollier, however, maintained his position, and believed it to be strengthened by the fact that rat-tails had been transplanted,§ and had grown as well after as before transplantation.‖

Attempted Transplantation of Bone and Periosteum in Man.—As one might expect, when the materials furnished by experiment on the lower animals are meagre, they are more so when looked for in man. Passing the fabulous account of transplantation of bone¶ dating from

* "Pour nous mettre à l'abri des objections qu'on adressait aux experiences de nos prédécesseurs, nous transplantâmes dès 1858 des os entiers sous la peau ou dans d'autres régions étrangères à l'ossification, et nous pûmes nous convaincre que la greffe est bien réelle."—Ollier, *loc. cit.*, vol. i, p. 420; also in "Comptes Rendus" de l'Institut, 28 février, 1859.

† Ollier mentions the following experiments:—

"Bagdanowski en 1860 ('Petersburger Medicin. Zeitschr.') a transplanté sur huit chiens des fragments de diaphyse du radius et du cubitus. L'os transplanté ne s'est pas greffé, mais autour de la substance osseuse il s'est formé dans certains cas une capsule ostéo-fibreuse qui se continuait avec les bords de l'os ancien."

"Middeldorpf, ayant introduit des morceaux de radius de pigeon dans la cavité abdominale d'un autre pigeon, vit l'os transplanté subir la dégénérescence graisseuse, après s'être entouré d'une capsule cellulo-fibreuse isolante."—Günsburg's "Zeitschrift für Klin. Med.," 1852.

‡ "Die Osteoplastik in ihren Beziehungen zur Chirurgie und Physiologie."—"Archiv für klinische Chirurgie," Langenbeck, 1863.

§ Bert, "De la Greffe Animale," 1863, Thèse de Paris; "Journal de l'Anatomie et de la Physiologie de Robin," 1864; "Comptes Rendus de l'Institut," 1865.

‖ Ollier only succeeded in the rabbit in transplanting portions of bone; he never was able to do so in the dog, as the following will show:—" . . . nous n'avons pas, du reste, réussi à greffer des os entiers chez le chien."—Ollier, *loc. cit.*, vol. i, p. 421.

¶ "Un ecclésiastique nommé Kraanwinkel, racontait, du temps de Job-à-Méékren, qu'étant en Russie un Seigneur de cette nation reçut d'un Tartare un coup de sabre à la tête, lequel lui enleva une assez grande étendue du cuir chevelu et la portion osseuse correspondante, qui restèrent perdues sur le champ de bataille. Le chirurgien, pour boucher l'ouverture du crâne, détacha de celui d'un chien, tué à cet effet, une pièce d'os de mêmes forme et dimension que celle qui manquait, et l'arrangea si bien que le blessé fut parfaitement guéri . . . . Bientôt les foudres de l'Eglise furent lancées contre lui. Il fallut pour rentrer dans la communion des fidèles qu'il se fît retrancher l'immonde dépouille du chien, quoique solidement consolidée,

the seventeenth century, the attempt made by Percy to transplant ox bone into man is arrived at, and seems to be the first reliable experiment in that direction.* On two successive occasions he placed in a human lower limb a portion of the tibia of an ox, hoping that it would fill up a gap left by a compound fracture attended with loss of bone. Those attempts were futile. Ollier likewise met with failure in endeavouring to transplant a portion of human periosteum from one part of a man's body to another.† And a like result ensued on an attempt made by another surgeon to introduce a portion of dog's bone into the human body.‡ Some months previous to this last experiment, I transplanted a portion of one of the flat bones of the canine skull into a gap in the skull of a man.§ Two-

et qu'il se soumît à un traitement plus conforme au caractère de chrétien."—"Dictionnaire des Sciences Médicales," livre XII, p. 355.

* Nous avons deux fois fait cet essai avec de bouts d'os d'avant-bras, pris sur un bœuf, au moment où il venait d'être abattu. Ces bouts avaient été sciés avec soin ; ils étaient encore recouverts d'une partie de leur périoste, et nous les avions interposés entre les fragments de la fracture, arrangés pour les recevoir. Mais notre entreprise, ainsi que nous devions bien nous y attendre, a échoué, et loin que nos pièces d'os de bœuf, après avoir été en place une fois quinze jours et une autre vingt, eussent présenté le moindre vestige d'adhérence et de cicatrization, nous pûmes remarquer, en les retirant, qu'elles avaient manifestement nui au développement vasculaire des surfaces sur lesquelles elles avaient porté et que leur séjour trop prolongé eût fait avorter l'œuvre du cal ou de la consolidation."—"Dictionnaire des Sciences Médicales," livre XII, Art. "Ente Animale," p. 358.

† "13 Mai, 1865.—*Transplantation.*—On fait une incision de 9 centimètres sur la face interne du tibia droit, immédiatement au-dessous du cartilage de conjugaison supérieur, s'éloignant ainsi suffissamment du genou pour ne pas y déterminer une arthrite et se rapprochant le plus possible du cartilage de conjugaison, afin d'avoir la portion de perioste la plus active du tibia. On détache ensuite avec la sonde-rugine un morceau de périoste long de 8 centimètres, large de 2 centimètres, et on le laisse adhérent par un seul point à sa partie supérieure. Faisant ensuite deux incisions transversales de 1 centimètre et demi à 2 centimètres, l'une à la racine du nez, l'autre à 7 centimètres au-dessus sur la partie moyenne du front, on creuse, avec une pince dont les deux branches sont tennues rapprochées l'une de l'autre, une gaîgne dans le tissue cellulaire sous-cutané. On sépare alors le morceau de périoste de ses dernières attaches, et on le transporte dans cette gaîgne . . . . 22 Mai.—Le lambeau paraît avoir descendu ; son extrémité fait plus de saillie par l'ouverture inférieure ; on croit inutile de laisser séjourner un lambeau qui paraît mortifié et qui joue le rôle de corps étranger. On le saisit avec des pinces et on l'arrache brusquement ; le malade pousse un cri, et l'on s'aperçoit que le lambeau tenait encore par trois points qui avaient contracté des adhérences vasculaires."—Ollier, *loc. cit.*, vol. II, pp. 437-8-9.

‡ In September, 1874, Dr. Paterson removed a complete cylinder of the radius of a dog, measuring three-quarters of an inch, and placed it into a gap existing in the radius of a man. The transplant was not successful, the osseous cylinder coming away sometime after in an eroded condition.—"Lancet," October 19, 1878.

§ In March, 1874, while acting as surgeon to the Western Infirmary Dispensary, a man presented himself with a gap in the vault of his cranium, resulting from a wound received some weeks previously. From this wound a detached portion of the

thirds of the graft remained in the tissues, apparently becoming incorporated with them and forming a firm hard layer. No opportunity was afforded of demonstrating by an incision the exact condition of the graft. Bearing in mind the repeated statement of Ollier, that osseous grafts taken from one species and transplanted into another species would not live, I am inclined to reserve expressing a positive opinion on the success of the graft in this instance.

Historical Resumé.—The position of transplantation of bone is, therefore, as follows:—In the lower animals Ollier has transplanted periosteum and osseous tissue, and among many failures he succeeded in one instance in forming an osseous ring from grafted periosteum, and in another in transplanting a portion of bone from the one radius to the other of the same animal. Wolf, of Berlin, repeated Ollier's experiments, and stated that he never obtained an osseous growth from any transplant. In man there have been several attempts to transplant periosteum* and bone, which, with one exception, have been attended with failure. The exception—the case mentioned of grafting dog's bone into a human skull—has not been clearly demonstrated.

Points to be solved regarding Transplantation of Bone.

It may be concluded, therefore, that the subject of transplantation of bone and its subsequent growth have not yet been convincingly proved, and that Ollier's experiments require further confirmation.

The questions which are still at issue are—first, will bone grow after transplantation? Will it add any osseous increment to its bulk?

Second, are the facts derivable from animals applicable to man?

internal table of the skull protruded, which, when removed by the fingers, exposed the pulsating brain destitute of its dura mater, but covered by the ordinary exuberant granulations. A somewhat irregular aperture, an inch by half an inch, was left in the osseous wall. In order to fill up this gap a dog six weeks old was taken, and a portion of its parietal containing its ossifying centre was removed along with its periosteum. It was shaped into the form of the gap, and inserted into the osseous aperture in the man's skull. A small hole was left for drainage from the interior of the bone. Before transplanting, the skin which had been adhering to the edges of the bone was elevated, and the bones were refreshed. After transplantation the skin and tissues were drawn together over the graft, and united by sutures. Three weeks after, about a third of the graft was found to have become necrosed, and shortly after this part separated. The remaining two-thirds adhered firmly. Soon after the removal of the necrosed part the wound completely closed. On pressing the finger down on the skull, there seemed to be a little osseous elevation at the part where the graft remained; and as far as the finger could detect through the scalp, the gap was filled by a hard resisting layer, apparently bone.

* In a letter just received from Professor Ollier, he states that he has endeavoured to transplant periosteum removed from the limbs of condemned criminals, placing it in granulating wounds and ulcers. In one instance he found a hard part of cartilaginous consistence, but the after result he was not able to follow.

It is highly necessary to ask this question, as Ollier admits that though successful in his osseous transplants among rabbits, he did not succeed in transplanting portions of bones in dogs.

If the first two questions be answered affirmatively, the third follows:—though the possibility of bone showing indications of growth after transplantation be admitted as a physiological fact, can it furnish any practical result?

Facts tending to show the probability of Transplanted Bone Living.

Facts presented by my surgical observations, especially of compound fractures treated antiseptically, go far to support the belief that transplanted bone is capable of living and growing. Stated briefly they are as follows:—

Portions of completely detached bone covered with periosteum, after being washed with carbolised solutions, have been replaced, and they have lived, thrown out callus, and increased in thickness, uniting at the same time firmly to the neighbouring bone.

A portion of bone, destitute of periosteum and completely detached from the soft tissues, has been removed and placed at a short distance from its original site, where it has adhered, united with the neighbouring bone, and apparently grown thicker in bulk.

The cylindrical extremity of a fractured humerus for over 2 inches was completely stripped of periosteum, round its whole circumference; the soft tissues which covered it in were reduced to pulp, yet this portion of bone, entirely destitute of periosteum, lived and united firmly with the shaft.

Portions of fingers and toes, containing their bones, have reunited after having been completely detached, and have grown into useful members.

The three phalanges of a finger were entirely stripped of the soft tissues and vascular supply; the bones with their ligament and tendons projected as if in an anatomical specimen. The soft parts were put over it like a glove, and both lived and grew.

These were at least sufficient to cause one to look hopefully on transplantation of bones.

Consideration of best Method of Transplantation of Bone.

What elements of Bone are best Suited for Osseous Transplants?—In considering the suitability of the various osseous elements for transplantation, it was evident that periosteum was best suited as far as its vascularity was concerned; but if it were alone taken, it was equally clear that at best only a very thin osseous layer could result, a layer so thin as to be totally inadequate for the formation of a bone resembling the human humerus. It is admitted that the true bone-forming elements of the periosteum are confined to the layer which is

in immediate contact with the bone, and which sends prolongations into the Haversian canals. Now, if one attempts to elevate periosteum from healthy bone, portions of the osteogenic layer are apt to be left adhering to the osseous surface, the capabilities for bone formation of the periosteal graft being thereby deteriorated or destroyed.

The whole of the Osseous Elements ought to be included in Transplants of Bone.—In taking the calcareous matter along with the periosteum, the whole periosteal osteogenic layer is preserved, the calcareous matter at the same time forming a support to and mould for the new bone. Besides, the prolongations of periosteum contained in the Haversian canals will proliferate if they have a free surface to expand into, and therefore the soft parts inclosed in the calcareous matter are important elements in the graft. The medulla is also under certain circumstances capable of producing bone; and, through its intermediary, the vascularity of the graft might the more easily be effected. It was, therefore, determined that a graft should be composed of the whole of the osseous elements, periosteum, calcareous matter, and medulla.

Failure of Osseous Transplants due to want of Nutrition.—In transplanting bone the paucity of its vascular elements made the re-establishment of its blood supply the first point to be considered. Failure has attended attempts at grafting cylindrical portions of the long bones, owing to the length of time necessary to establish the blood supply through the periosteum to the more distant and dense portions of bone.

How to Maintain Nutrition after Transplantation.—In order to place transplanted bone in the most favourable conditions for living, it ought to be divided into small pieces, so that the blood effused from the intermuscular space into which the bone would be implanted, may permeate between the individual fragments, and thereby afford a medium for the establishment of vascular connexions, and the supply of nutriment to the individual pieces of bone. Though the transplant consisted of dense osseous tissue, in its divided form it would somewhat resemble cancellated tissue. The re-establishment of the blood supply to the grafts would thus be hastened and facilitated, and any portion of the graft which was not suitable could be easily thrown off without involving the whole.

Other reasons for Dividing Bone into Small Pieces.—On other grounds the division of the osseous transplant into small portions is advantageous. Whether the leucocytes in the effused blood clot may or may not be transformed into bony tissue, the blood clot itself when small in quantity forms an excellent matrix for the proliferation of the osteogenic elements. Again, the division of the bone into small pieces not only makes the individual vitality more certain, but it also supplies a greater number of proliferating osseous centres. In the case of the calcareous tissue there is this further potent reason,

that the osteogenic cells contained in the Haversian canals cannot proliferate (except at the expense of the hard tissue) as long as they are bound in—imprisoned by—calcareous walls; the division of these hard walls gives the soft tissues contained therein room to proliferate. Besides, the graft when composed of small portions of bone, is more easily moulded into any form which the surgeon may desire.

It was resolved to give practical expression to these views in the following case. In order to place all the particulars of the case before those interested, the history is given in detail.

Case in which Interhuman Transplantation was Successfully Performed.

William Connell, aged three years, was admitted into the Royal Infirmary, Glasgow, under my care on the 17th July, 1878, in a much emaciated and exhausted condition arising from suppuration in connexion with necrosis of the right humerus.

He came of healthy, though poor and itinerant parents. He presented the appearance of a much neglected child. Constitutionally he was weak, his pulse a mere thread, his cheek surmounted by a hectic flush, and on slight effort beads of perspiration bedewed his forehead. The right upper arm was greatly distended, and fluctuant from shoulder to elbow. About the middle of the upper arm there were two cicatrices, which were stated to be the marks of recent openings through which pus had escaped to within a week of his admission to the hospital. Toward the middle of the outer aspect of the arm, the skin, including these cicatrices, was for about a couple of inches thin and reddened. A puncture was made at this point, giving vent to fourteen ounces of thin fœtid pus. When the abscess was evacuated the shaft of the humerus was found to be totally necrosed, and already separated from its head at the epiphyseal junction. At the condylar epiphyses slight crepitation was elicited. From the condition of the bone, as well as from the few items of history which could be relied on, it was evident that the destruction of the bone had occurred from four to six weeks previously. After the pus had been evacuated, and the distention of the soft parts had thereby been reduced, the shaft of the humerus was exposed through an aperture measuring nearly an inch square, situated on the outer aspect of the arm. The bone at this point was dark-coloured and fœtid. The arm was dressed, the patient was placed on generous diet, and otherwise attended to in the hope that his strength might improve, and that he would thereby be placed in a better condition for the removal of the necrosed shaft. Notwithstanding treatment, the daily discharge of fœtid pus was great, and as the amount was not much lessened at the end of three weeks, it was considered advisable to remove the source of irritation.

Necrosed Bone Removed.—On August 7th, 1878, the part of the necrosed bone exposed at the aperture already mentioned was divided by the bone forceps. The upper part of the shaft was then caught by lion forceps, rotated in order to loosen its periosteal attachments, and then pulled out. The lower portion was similarly dealt with. The two portions removed comprised the whole humeral diaphysis. The periosteum opposite the opening in the soft parts was nowhere seen or felt, its place being occupied by granulation tissue. Granulations likewise lined the tunnel from which the bone was removed; but at the upper part toward the head of the bone, the finger detected periosteum with rough calcareous matter adhering. The apertures left by the removal of the shaft were stuffed with carbolised lint, and the arm was carefully fixed on a splint. The suppuration continued profuse for about a fortnight, then gradually diminished. The tunnels left by the withdrawal of the bone were kept patent as long as possible, but they slowly coalesced from the epiphyses toward the superficial openings without the formation of new bone, except for a short distance from the head of the humerus. After the first fortnight the patient's constitutional state improved under good diet, cod liver oil and lime water. Local applications, with a view of stimulating the bone growth, were tried, but were found unavailing. The wounds were quite healed on 1st November, and he was dismissed from the ward on the 23rd November, 1878, with about an inch and three-quarters of shaft attached to the head of the bone; even this was thin and tapered. There was no bone from this down to the condyles. There was, therefore, over two-thirds of the humeral shaft wanting. A month after (in December, 1878), he was seen, and the tapered portion had increased by about a quarter of an inch. The measurement from the acromion process to the end of this tapered process was 2 inches. He was seen monthly for some time, but no further growth of bone followed.*

Appearance of the Arm one year and three months after.—On November 7, 1879, the patient was re-admitted to the hospital. The bone had not grown further, though one year and three months had elapsed since the subperiosteal resection of the humerus. When the limb was placed hanging down by the side, the measurement from the tip of the acromion process to the distal extremity of the proximal portion of the humeral shaft was nearly 2 inches. In form, this upper fragment

* Cases of subperiosteal resections of the humerus have occurred in which the bone has not been reproduced. Thus, Nedöpil performed a subperiosteal resection of the humerus in a boy twelve years of age, the shaft not being reproduced. In order to render this boy's arm of some use an orthopœdic apparatus, devised by Billroth, was applied. Neudörfer also mentions a case in which the humeral shaft was not reproduced after subperiosteal resection. (Professor D. Vogt, "Die Chirurgischen Krankheiten der Oberen Extremitäten," p. 225, paragraph 212.)

was conical, tapering from the head to a narrow spike-like distal extremity, which appeared, when he attempted to raise the arm, as if it would penetrate the skin. From this down to the condyles there was a complete absence of bone, there being nothing but soft tissues in the gap. The muscular power was good, but when he attempted to raise his arm a contraction of the muscles took place, the condyles being drawn towards the proximal extremity, while some fibres of the deltoid raised the spike-like process of the upper portion, causing it to project as if about to penetrate the skin. Here the action ceased, the soft parts in the gap appearing like a rope during the contraction. He could not raise his forearm to his breast. If one caught the arm firmly with the hand so as to keep the condyles fixed and separate from the upper fragment, then the patient could elevate the forearm towards his chin. The power was there; the lever and fulcrum were wanting. An apparatus supplying these might have been devised, but, if such an expensive article could have been obtained, it would have been necessary to renew it often as he grew older. On account of his social condition it would have been impossible to secure this and the after attention necessary. The only other alternative was to supply the gap by transplantation of bone.

In my wards there were numerous cases of marked anterior tibial curves, from which wedges of bone had to be removed, and it was determined to utilise these wedges as transplants.

Transplantations of Bones.

Transplantation of two Wedges of Bone.--On November 9th, 1879 (one year and three months after the removal of the necrosed shaft) an incision was made down to the extremity of the upper fragment. This extremity was found to be cartilaginous for fully a quarter of an inch. This cartilaginous spike-like process was removed, leaving then a portion of bone which measured $1\frac{3}{4}$ inch from the tip of the acromion process. From this point a sulcus about 2 inches in length was made in a downward direction between the muscles. The former presence of bone was nowhere indicated, and the sole guide as to the correct position into which the transplant was to be placed was an anatomical one. After the sulcus was formed, the hæmorrhage was fully arrested, and an aseptic sponge was placed in the gap, which was then ready to receive the bone.

Two wedges were then removed from the tibiæ of a patient six years of age, affected with anterior tibial curves. The base of these osseous wedges consisted of the anterior portion of the tibia, along with its periosteum, the wedges gradually tapering towards the posterior part of the tibæ.

They were removed, then cut into small fragments with the chisel, and immediately thereafter they were deposited in the sulcus in the

boy's arm. They were kept under the spray from the time they were removed from the tibiæ until they were covered by the soft parts of the arm and its antiseptic dressing. The time occupied in removing the wedges, cutting them into fragments, and placing them in the living tissues of the arm, was about two to three minutes. A drain of horsehair was inserted, and the wound was carefully stitched and dressed.

The wound healed without pus production. The patient's temperature remained normal throughout.

A month after the operation the arm was looked at for the third time, when the transplant felt firm and united.

Result of the first Transplant.—Two months after, it was thoroughly examined, when a portion of the bone, 1 inch in length and, as far as could be measured, nearly three-quarters of an inch in thickness, was found firmly attached to the upper fragment of the shaft. In running the finger from the head of the bone towards the graft, the latter could be distinguished by its greater breadth. At this time, instead of the former sharp spike, the upper fragment ended in an obtuse terminal.

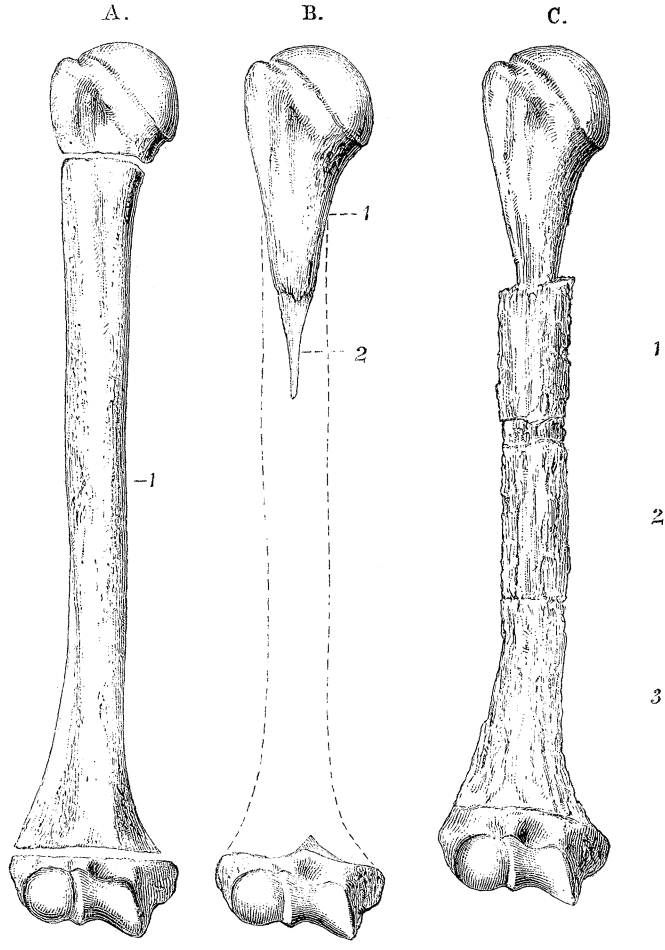
Placing the arm by the side, the measurement from the tip of the acromion process to the extremity of the bone was now $2\frac{3}{4}$ inches. That was a distinct gain of 1 inch in length. The arm was shown in this condition to the Glasgow Pathological Society.

Second Transplant.—On February 1st, 1880, the upper fragment was laid bare, the extremity of the first graft was exposed, and found to be covered by a fibrous vascular membrane, which had to be elevated in the same way as periosteum. Under this there was distinct calcareous tissue, which had all the appearance of living bone. A sulcus was made between the muscles for the reception of fresh grafts, which were obtained from a patient five years of age, affected with anterior tibial curves. The wedges were divided into larger pieces than the first graft.

Some of these measured half an inch by a quarter of an inch, but the majority were about one-eighth of an inch by one-sixteenth.

The child kept well up to the third week, when the temperature suddenly rose, and on examination some pus was found on the dressing, and one of the larger pieces of bone was discovered on the surface of the wound. Afterwards several portions of bone were shed. The portions were mostly the larger pieces of the graft. The smaller fragments remained. Thus about one-third of the second graft came away. The portions of bone which were shed were eroded, small hollows being formed on their surface, filled with granulation tissue. After these parts were removed, there was a distinct firm mass of bone left.

Result of the second Transplant.—On April 20th (about two and a half months after the second graft) the measurement from the tip of the



Schematized Drawings.

A.

1. Necrosed diaphysis, which was removed.

B.

1. Portion of shaft attached to head reproduced from original periosteum.
2. Cartilaginous terminal removed before first transplant.

C.

1. First graft.
2. Second graft.
3. Third graft.

acromion to the extremity of the shaft was 4 inches, being a gain of an inch and a quarter.*

The third Transplant.—On 9th July, 1880, the third transplant was performed. On this occasion the condyles were exposed, and a cartilaginous spike an eighth of an inch in length, situated between the condyles was seen to be the sole representative of the shaft from that direction. This cartilaginous spike was removed, and the upper portion of the condyles was refreshed. A sulcus between the muscles was then made from the condyles to the distal extremity of the upper fragment. Two osseous wedges were removed from a patient aged nine years, affected with anterior tibial curves. Each of those wedges was half an inch thick at its base, and measured three-quarters of an inch in length from apex to base. They were divided into smaller fragments than the last, and were laid into the groove between the muscles. The wound healed, all but a small part of the lower border, from which four small portions of dead bone were removed at the second and third dressings. About the middle of August there remained a firm osseous ridge running from the condyles towards the upper fragment. At this date the patient was dismissed from the hospital, and returned on 27th October, 1880. On his return the last transplant was found to be still firm, and measuring from $1\frac{3}{4}$ to 2 inches in length. It was also thicker than that resulting from the others. The proximal and distal grafts were now touching and could be rubbed together.

Two Ends of transplanted Bones refreshed.—It was thought advisable to refresh the ends of these grafts, and bring them together by sutures. This was done on October 31st, 1880 (over three and a half months from the last graft, and about one year from the time of the first graft). Both extremities were seen to be distinctly osseous, and appeared to be living bone. They were covered by a fibrous vascular membrane, resembling periosteum. It was somewhat difficult to secure correct apposition, and some portions had to be removed by the bone forceps in order to permit of better adaptation. Six weeks after, when the wound was looked at, union was not perfect. The extremities of the bones were rubbed firmly together, and on January 9, 1881, union was found to be taking place. In order to hasten it

* On July 6th, 1880, a little girl was admitted into the ward suffering from a crush of the upper arm received by a railway accident. Amputation at the upper third of the arm had to be performed. The lower third of the humerus, though somewhat crushed, was so nearly what was wanted to fill up the gap in the boy's arm, that it was determined to transplant it. Owing to the manner in which it fitted into the gap in the boy's arm it was considered advisable, in an experimental sense, not to divide it into small pieces, but to preserve it entire. It was transferred on July 6th, but three days after the periosteum was found to be in great measure stripped, leaving the cylinder bare. The bone was therefore removed; the granulations in the sulcus between the muscles scraped, and what may be regarded as the third regular transplant proceeded with.

a couple of pegs were inserted with the aid of a drill. They were kept in for five weeks, and when removed the bone was found firm. At the beginning of March, 1881, the bone was found firmly united, from the head to the condyles, and measured 6 inches; while the left humerus measured $6\frac{1}{2}$ inches, that is to say, half an inch longer than the transplanted one. On rotating the condyles the head of the humerus responded to the movement. The patient could lift his arm to his head and otherwise use it.

Résumé.—This was a case of extensive suppurative periostitis followed by complete necrosis of the humeral diaphysis. The necrosed humerus was divided at its exposed part, and each half was pulled out from what was supposed to be its periosteal sheath; but on withdrawal doubts were expressed as to whether the periosteum had not, for the most part, undergone destruction. As a result, at the proximal extremity bone was formed, of a pyriform shape, tapering from the head toward a point an inch and three-quarters from the tip of the acromion process. This left over two-thirds of the shaft wanting. There was no further attempt at bone formation. A year and three months afterwards, the state of the parts remained the same. After this time the first transplant was performed. In making the sulcus for the reception of the graft, reliance had to be placed on the anatomical relations as to the correct position for the graft, as there was no trace of periosteum or fibrous structure to indicate the former whereabouts of the bone. Portions of human bone were transplanted on three different occasions. The grafts were obtained from patients affected with anterior tibial curves, from whom wedges of bone had to be removed for the purpose of straightening their limbs. These osseous wedges, with their periosteum, were each divided, after removal, into many small pieces, which were immediately placed in the sulcus prepared for them in the boy's arm. These small portions united together and adhered to the head of the humerus above and the condyles below, ultimately forming a solid rod, only half an inch shorter than the humerus of the opposite side. The transplantation of bone converted a useless arm into a thoroughly useful one.

Deductions from these Transplantations.

Though the foregoing is only a single case, as far as the individual is concerned, yet from the number of transplants which have been performed it may be regarded as a series of experiments. It is now necessary to ask, what conclusions may be drawn from the data supplied by these experiments? Before answering these, the way may be cleared by reference to two points. First, some who have heard of this case without having seen the operations, have asked, whether it was not possible that some old periosteum remained in the arm and produced the new bone, the operation of transplantation having only

acted as a stimulus to it? In answer, it must be borne in mind, that had periosteum existed, between the condyles and the upper part of the humerus, it had ample opportunity of revealing itself by osseous growth, during the fifteen months which elapsed between the removal of the dead bone and the transplantation of the new. Again, in opening up the sulcus between the muscles for the reception of the transplants, neither periosteum nor any vestige of like fibrous membrane was seen; so much so, that it was only by recognising the relative positions which the muscles ought to occupy toward the humerus, that a guide to the correct position of the transplants was found. Further, the growth of bone in the arm was at first only commensurate with the transplants. There was no indication of osseous growth in the vicinity of the transplant which might have arisen from the "supposed stimulated periosteum." Finally, the solid humerus still retains the irregularities of shape which the transplants were permitted to assume in the tissues. So that there is not an iota of fact to support the supposition that the new bone grew from old periosteum.

Transplants not being Absorbed.

Secondly, it is stated that though transplanted bone may be retained in the tissues, yet it may be simply encapsuled and be undergoing slow absorption. If absorption were taking place the changes so brought about ought to be apparent by this time. The first graft was made one year and five months ago, the last nine months since (this is written on 12th April, 1881), and the bone formed after the healing of the wound made for the reception of the graft has not only maintained its original dimensions but has grown. This sufficiently sets at rest the question of absorption of the transplanted bone.

The way being thus clear, the conclusions drawn from the data supplied by these experiments may be considered. To commence with the questions in the order in which they are placed at the beginning of this paper. What evidence do these experiments afford as to the growth of transplanted bone?

Proofs of Growth of Transplants.

When from six human lower limbs six wedges of bone (along with their periosteum and marrow) are removed, divided into small pieces, placed in the arm of a boy, in an intermuscular space freshly opened by the scalpel for their reception; and when it is seen that, with the exception of a few fragments of bone which were shed, the whole of the grafted portions united one to another and to the ends of the original bone; making in all four and a-half inches of osseous transplant, whereby a united humerus has been formed, which he moves and uses as the other arm; it may be concluded that the trans-

planted bones have lived and grown. Before these transplanted portions of bone could have united together, there must have been a proliferation of the bone-forming elements contained in the grafts. That the development of fresh bone originated in the transplants is typically illustrated, where the second transplant united to the first by one end, while its other extremity was free in the tissues; so that it did not come into contact with the original bone at any part. Yet this transplant consolidated just as well as the first or second transplant did. As further illustrations of the vitality of the transplants and the growth of new bone from them, there is, firstly, the evidence derivable from the callus thrown out between the second and third transplants, after their extremities were refreshed, the same phenomena being observed here as in an ordinary case of ununited fracture. Secondly, the bones became sensibly thicker at the point where they were drilled for the reception of the pegs. All these are evidences of actual growth of bone from the transplants.

Vascularity of Transplants.

When the extremities of the second and third transplants were refreshed, the appearance of both bones was that of living osseous tissue; surrounded by a thin fibrous vascular membrane closely adherent to the bone, and which bled when it was scraped up, much in the same way as periosteum would under similar circumstances. This membrane did not resemble the thick semi-vascular capsule which is found surrounding dead tissue in process of being absorbed.

These facts being derived from the interhuman transplantation are, as they stand, a sufficient answer to the second question; while the utility of the arm after restoration of two-thirds of the humeral shaft establishes the practical results of the operation.

The method of division of the bone into small pieces prior to transplantation, and the *à priori* reasons for doing so, have been borne out by the success which has attended the practical performance of the operations.

Conclusion.

From the foregoing the following may be formulated :—

1. Transplanted bone is capable of living and growing.
2. Interhuman transplants of bone live and grow.
3. Interhuman osseous transplants are capable of being put to practical uses beneficial to mankind.
4. The whole of the osseous elements ought to be included in the transplants.
5. The most successful mode of transplanting bone is to divide it

into small fragments with a sharp instrument before inserting it into its new locus.

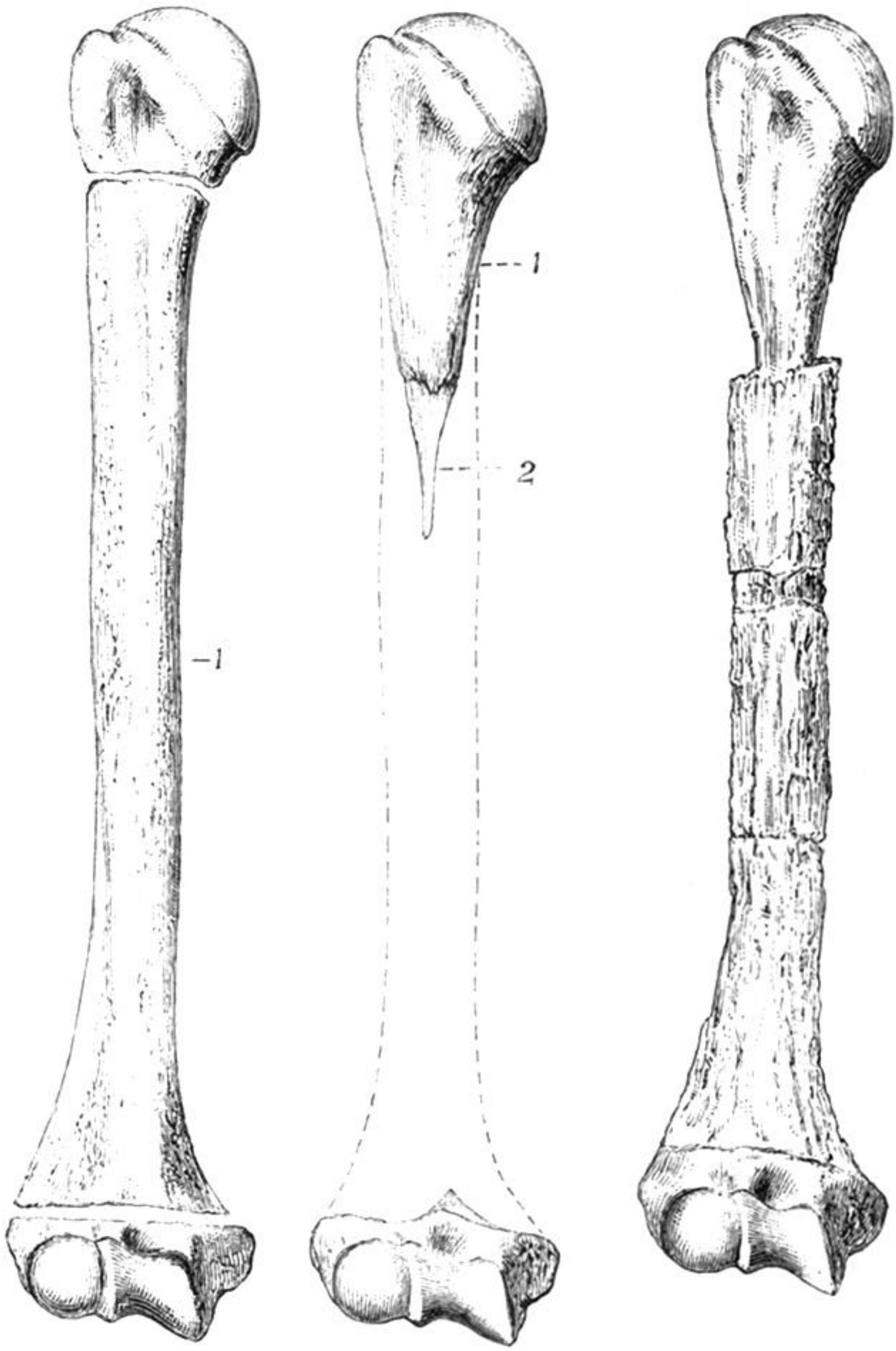
6. In order to insure the success of the graft the transplantation must be conducted antiseptically.

V. "Experimental Determination of the Velocity of White and of Coloured Light." By Dr. J. YOUNG, F.R.S., and Professor G. FORBES. Received May 17, 1881.

(Abstract.)

The method employed in this research to measure the velocity of light resembled the method of M. Fizeau, subsequently employed by M. Cornu. A revolving toothed wheel is employed in the same way to alter the intensity of the light reflected from a distance. In the present method, however, there are two distant reflectors instead of only one. They are separated by a distance of a quarter of a mile. The observing telescope and the two reflectors are almost in the same line. The observer sees two stars of light which go through their phases with different periods as the toothed wheel is revolved at increasing speeds. One star is increasing, while the other is diminishing, in intensity, with increase of speed of the toothed wheel. The speed required to produce equality of the lights is determined by means of a chronograph. By choosing such a speed as gives a maximum of one star at the same speed as a minimum of the other, a pair of observations eliminates all cause of doubt arising from varying brightness in the stars, and ratio of the width of a tooth to the width of a space. The distances were observed by triangulation with the Ordnance Survey 18-inch theodolite, using as a base line a side of one of the Ordnance Survey triangles. The source of light was an electric lamp. The velocities (uncorrected for rate of clock, and reduction to a vacuum) measured are as follows:—

	187,707
	188,405
	187,676
	186,457
	185,788
	186,495
	187,003
	186,190
	186,830
	187,266
	188,110
	188,079
Mean.....	187,167 miles a second.



Schematized Drawings.

A.

1. Necrosed diaphysis, which was removed.

B.

1. Portion of shaft attached to head reproduced from original periosteum.
2. Cartilaginous terminal removed before first transplant.

C.

1. First graft.
2. Second graft.
3. Third graft.