

## The Classic

### Transplantation of Entire Bones with their Joint Surfaces\*

A. Bruce Gill MD (1876–1965)

The 6th President of the AAOS 1937

Arthur Bruce Gill was born in Western Pennsylvania and obtained his undergraduate degree at Muskingum College in New Concord, Ohio [1]. He then obtained his medical degree at the University of Pennsylvania in 1905, interned there, and remained on the staff for 47 years. He became the third chairman of that department in 1920. He was active in a large number of organizations well into the 1950s.

One writer noted he “...was not a prolific writer, but whatever he wrote was extremely clear and well prepared. There are sixty-nine publications listed under his name in the Index Medicus and Quarterly Cumulative Index...” [1] A substantial number of those publications related to problems of childhood and at least six related to new procedures. Yet, Dr. Gill was wary of new operations. In his Presidential lecture at the AAOS in 1938, he wisely commented, “Let us beware of adopting new methods too hastily.” He added, “Are too many operations performed in the practice of orthopaedic surgery?...many of our young men believe that they can attain distinction only by the invention of a new operation,” and recognized the need to refrain from “fads and fancies” [3].

We republish an abridged version of experiments he performed in 1914 in which he transplanted whole bones with their joint surfaces within one animal [2]. Portions excluded include his description of the six operations and their results, and a scholarly discussion of the knowledge of transplantation and regeneration at the time. (Interested readers in such material would be well advised to also review an extensive discussion of the knowledge of bone biology in Sir Arthur Keith’s classic monograph, “Menders of the Maimed” [4].) Dr. Gill concluded fresh bone with cartilage surfaces was readily transplantable as long as



Arthur Bruce Gill, MD is shown. Photograph is reproduced with permission and ©American Academy of Orthopaedic Surgeons. *Fifty Years of Progress*, 1983.

“periosteum, medulla, and bony tissue” were all included in the graft. Immunology as a field was not well developed at the time, nor the known problems with transplantation between individuals and species. Nonetheless, his experiments formed a basis for the principles of whole bone transplantation.

Richard A. Brand MD

#### References

1. Arthur Bruce Gill, 1876–1965. *J Bone Joint Surg Am.* 1966;48:394–396.
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3. Heck CV. *Commemorative Volume 1933–1983 Fifty Years of Progress.* Chicago, IL: American Academy of Orthopaedic Surgeons; 1983.

4. Keith A. *Menders of the Maimed*. London, UK: Henry Frowde; 1919.

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The following experiments in bone transplantation were undertaken to determine whether or not it is possible to secure the healing in of entire bones with their articular surfaces, and whether or not such bones, if they do become healed in, will remain alive and unabsorbed, and, finally, to observe any other conditions that may have a bearing upon the subject of bone transplantation in general.

Full-grown dogs were operated upon under complete surgical anaesthesia by ether. The second long metatarsal bone was excised in the front paws and each one was implanted in the opposite paw. The ends of the bone were held in the position by chromic catgut sutures. Tendons and fascia were sutured over it with interrupted sutures of silk floss. Asepsis was attempted by shaving the paws and painting the skin with tincture of iodine and by clamping the margin of the incision to sterile towels. After the incision was closed it was painted with tincture of iodine. No dressings were applied and the dogs were permitted to walk about. This they usually did on the day following operation without any evidence of pain.

*Summary.*—Eleven bones were transplanted. One dog was killed a week after operation, before healing in of the bones had occurred, and in another dog one transplant was removed under ether. The remaining eight transplants healed in after more or less suppuration of all wounds but one. The dogs were killed from seven to eight and one-half months after operation. One of the eight healed-in transplants was found to be almost all absorbed. Another is badly distorted and a second moderately changed as a result of osteomyelitis following operation, but they appear to be serving their function and they present evidence of new bone formation. The remaining five transplanted bones are practically normal in appearance. The articular ends of the bones are apparently normal and the joints have perfect function except in those cases where the end of the bone was destroyed by the suppurative process.

Microscopic examination of the transplanted bones that healed in with little or no suppuration of the wounds shows no evidence of dead bone anywhere. The bone cell as well as the cells lining the marrow cavity and the cells of the periosteum are well stained. If there was necrosis of the transplanted bone, the necrotic part has all been absorbed and replaced. The joint cartilage also appears normal.

The operations were performed by the writer without assistance. This rendered it necessary to fasten the paws of the dogs securely to blocks of wood. The straps caused venous constriction which prevented complete haemostasis and delayed the operations. These conditions probably caused the breaking down of the wounds and the subsequent suppuration. In experiment No. 6 this condition of venous construction was avoided and the one paw healed by first intention and the other healed promptly after it had opened up slightly. I believe that practically all cases could be operated upon with primary union under favorable conditions and consequent healing in of all transplanted bones.

The fact that so many of them healed in under unfavorable conditions and in the presence of inflection shows the marked resistance of the transplant. The articular ends of the bones and the joint cartilage show an equal ability with the remaining portion to maintain their life and resist infection. In these experiments the joints emerged from their trials in fully as good condition as the bones proper, and it should follow that the transplantation of half-joints and entire joints should present no greater difficulty or uncertainty than the simple transplantation of bones of equal size.

The fact that the dogs went about on their paws almost immediately following the operation does not necessarily affect the transplanted bone adversely. To the contrary, the functioning of the transplant may be a favorable factor in its life and regeneration.

These experiments would seem, therefore, to indicate that the smaller long bones with their articular surfaces are readily transplantable in the dog under unfavorable conditions, and that the joints are re-established and preserved thereafter.

In the successful transplantations the bones are found at the end of seven to eight and one-half months to be normal in outline and structure, to be living and to show no evidence of necrosis or absorption of any of their parts, in short, to be indistinguishable from normal bone. They have not been in contact with other bones except through their articular surfaces. We must therefore conclude either that the transplanted bone has retained life in itself or that it has been completely regenerated in all of its parts by a process of metaplasia of cells derived from the surrounding soft

tissue. Murphy's theory that a transplanted bone is only osteoconductive and that it must contact with fresh living bone is absolutely inapplicable to these experiments.

The metaplasia theory of bone regeneration from the surrounding connective tissue cells is maintained by Baschkirzew and Petrow, whose views, based on animal experimentation and clinical observations, are entitled to some consideration, if only to expose their fallacy. They state that the majority of bone transplants soon die: although a few stronger or better nourished ones may live a long time, until they also die of exhaustion. Some few heal in and regenerate new bone. Young connective tissue cells are the chief factor in the regeneration of new bone in a transplant which is imbedded in muscle. They penetrate into the vascular and the Haversian canals and are converted into osteoblasts and bone cells. The transplanted periosteum and endosteum become in part necrotic, while the remaining part is possibly capable of bone regeneration. But the persistence of such new bone is questionable and its differentiation from the bone which grows from the connective tissue cells is often impossible. The preservation of the periosteum is not essential to the life of the transplant, but it evidently is useful in causing more rapid union between the transplant and the surrounding tissues, in hindering resorption of the transplant, and in giving the first impulse to new bone formation.

This view of metaplasia does not agree with the views of most other investigators of this subject. Nor, if pushed to the limit, does it seem tenable. If the entire transplant has died and if later we find the transplant to be alive, then it is necessary to suppose that all its parts, periosteum, marrow, endosteum, bony tissue, have been regenerated from young connective tissue cells from the surrounding structures. But if these tissue cells are capable of such metaplasia, why do they not perform such function at all times, why do they wait until a dead transplant is thrust into their midst, or why do they not do it when a piece of decalcified bone of other porous substance is implanted? It becomes necessary to suppose that in some unaccountable manner the dying transplant stimulates the metaplasia. The same process must necessarily occur in every simple comminuted fracture. And all this theory in the face of the fact that bone contains within itself the elements necessary to its growth and regeneration. Why then should it borrow from the outside?

As a matter of fact, Baschkirzew and Petrow do not push their theory to its rational conclusion. They admit that certain parts of the transplant do regenerate new bone, but

say that such bone often cannot be differentiated from the bone which grows from the connective tissue cells. How then can they differentiate the latter from the former? Finally, the thorough microscopic studies of Plemister, Mayer and Wehner and many others show that certain parts of the transplant are osteogenetic. The latter investigators give careful consideration to Baschkirzew and Petrow's theory and point out the errors in their experiments in not excluding bone derived from the osteogenetic layer of the periosteum and from adjacent Haversian canals.

All the evidence and all the weight of authority is against the view of regeneration by metaplasia. We must conclude that a transplanted bone retains life in itself and is capable of its own regeneration as far as is necessary.

## Conclusions

Certain conclusions which are of practical clinical value in surgery are readily drawn from the above experiments and discussion.

- (1) Bone is only a particular form of connective tissue and is readily transplantable.
- (2) It contains within itself all the elements necessary to its life, function, and regeneration provided it receives sufficient nourishment.
- (3) Periosteum, medulla, and bony tissue should all be included in the graft.
- (4) After transplantation the bone grows and moulds itself to perform its function efficiently.
- (5) As early performance of function as is consistent with its fixation in its new position is of great advantage.
- (6) A mild infection is not necessarily fatal to the graft.
- (7) Transplantation of long bones with their joint surfaces is clinically possible. The inclusion of cartilage and joint surface in no way adds to the difficulty of the transplantation. While this statement is particularly true of the smaller bones, yet there seems to be no reason why as large a bone may not be transplanted with its joint surfaces as may be transplanted without such surfaces. Bier reports a large piece of tibia used to replace almost the entire shaft of the humerus, which has been under observation for 15 years. If a large bone should be transplanted it might be well to remove a portion of its shaft longitudinally in order to permit the ready access of a blood supply to the medulla.