MASSIVE OSTEOARTICULAR BONE GRAFTS
Transplant of the Whole Femur

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This paper reports seven cases of massive osteoarticular transplant, mostly for tumour. Five were in cases of giant-cell tumours, three in the upper tibia, one of the lateral femoral condyle and one of the olecranon. The sixth case was one of hydatid disease of the femur, and the seventh was a case of chondrosarcoma of the humerus. It is hoped that this work will help to establish the feasibility of massive or total replacement of bone and joint in weight-bearing limbs.

TECHNIQUES

Preparation of the grafts—Human cadaveric grafts were used throughout. In each case the cause of death was carefully investigated to exclude growths and infections. Grafts from cases of accidental death were preferred, but for legal reasons were difficult to obtain. Another good source was amputation for congenital defect. Blood grouping and immunological tests were not done.

The grafts are removed under sterile conditions within six hours of death; the soft tissues are carefully removed and the bones are put in sterile metal boxes which are then hermetically sealed. Before sealing samples are taken from the graft for bacteriological examination. The grafts are kept at temperatures of from −15 to −20 degrees Centigrade. They have to be used within six months. Before the grafts are used samples are again tested bacteriologically and the graft is rejected if there is any evidence of contamination.

Preparation of the bed—The limb is exsanguinated and the affected tissues are removed up to healthy bone. The soft tissues of the joint are dissected free and the capsule and ligaments are detached from their insertions. With lesions in the lateral tibial condyle the fibula is divided through its uppermost third and the proximal ends of the tibia and fibula are separated so as to give ample room. The semilunar cartilage is preserved in order to lessen the pressure on the articular cartilage of the graft. If one of the cruciate ligaments has to be cut this is done at its insertion in order to facilitate reinsertion. If necessary the patellar tendon is detached from its insertion and later reattached.

Implantation of the graft—During the resection a second team prepares the graft, which is thawed out in a solution of penicillin for 30 to 60 minutes before implantation.

After preparation of the bed and determination of the size of graft necessary the tourniquet is removed and complete haemostasis is secured. The graft is cut to size, put in and fixed to surrounding healthy bone by screws, bolts or nails. The soft tissues of the joint are then replaced around the graft so that the reconstituted joint is stable. After closure of the skin the limb is put in plaster.

Care after operation—The limb is kept in plaster for about sixty days, after which active and passive movements are encouraged. Then the patient starts to walk with the help of crutches, not putting weight on the affected limb. During the next months serial clinical and radiological examinations are done. Weight bearing is not allowed till one year after operation.

CASE REPORTS

Case 1—A man aged nineteen was admitted in October 1957 with a painful swelling of the right elbow following a blow sustained two months previously. Radiographs showed an osteolytic lesion involving the entire olecranon, bursting through the posterior cortex and entering the elbow joint (Fig. 1). Needle biopsy confirmed the diagnosis of giant-cell tumour.
Case 1—Giant-cell tumour of the olecranon. Figure 1—Before operation. Figure 2—State of graft one year after operation.
**Operation**—An S-shaped incision was made lateral to the triceps and the elbow. The ulnar nerve was separated from the tumour, which involved the soft tissues. The joint was opened and was found to be invaded by the tumour. The shaft of the ulna was cut through, and the upper fragment bearing the tumour was separated from the soft tissues and removed. The cadaveric ulna was inserted and was fixed in place with a medullary nail, two bone grafts being placed at the site of union of the graft with the lower end of the ulna. The biceps and brachialis muscles and the annular ligament were fixed to the graft with catgut sutures. The elbow joint was stabilised by a Kirschner wire passed through the olecranon into the humerus, and the ulnar nerve was replaced in its soft tissue bed. The wound was closed and the limb was immobilised in a plaster spica.

The plaster was removed three months after operation, when it appeared that incorporation of the graft was proceeding well. One year after operation there was good function: the elbow joint was stable and the range of movement was from 70 to 140 degrees. Radiographs showed the graft to be in place and apparently incorporated (Fig. 2).

**Case 2**—A man aged thirty-four was admitted in November 1958 with pain in the left knee following a blow one year before. There was tenderness over the lateral tibial condyle, with slight impairment of knee flexion. Radiographs showed an osteolytic lesion of the lateral tibial condyle (Fig. 3). Needle biopsy confirmed the diagnosis of giant-cell tumour.

**Operation**—A long incision was made lateral to the knee, the common peroneal nerve was identified and mobilised, the fibula was cut through and its uppermost third was retracted together with the tendon of the biceps. The lateral condyle of the tibia was seen to be invaded by tumour, which had considerably thinned the cortex. It was freed from the lateral cartilage and removed together with the tumour (Fig. 4). The latter had transgressed the midline of the tibia and was of yellowish colour. The defect was filled with a cadaveric graft that was held in place by a bolt and two screws. The articular cartilage of the graft was irregular, so it was removed and a flap of fascia was put between the graft and the semilunar cartilage. The fibula was replaced and was fixed in place with a medullary nail and with a screw securing it to the graft (Fig. 5). The wound was closed and the limb was immobilised in plaster.

The plaster was changed six weeks after operation and was finally removed six months after operation. Radiographs at that time showed some collapse of the graft, but six weeks later the patient was able to walk without difficulty. The knee joint was stable in extension and had an almost full range of movement.

Five years after operation the patient was working as a bus driver. He had no pain from the knee, which was stable and fully mobile, though showing some degree of valgus deformity. Radiographs showed that there had been good incorporation of the graft without further collapse (Fig. 6).

**Case 3**—A woman aged thirty-eight began in August 1961 to get pain related to the lateral aspect of the right knee. There was no swelling or restriction of movement, but there was marked tenderness over the lateral tibial condyle. A radiograph showed an osteolytic lesion in that condyle (Fig. 7). Needle biopsy confirmed the diagnosis of giant-cell tumour.

**Operation**—This was done three months after the onset of symptoms. A long incision was made over the antero-lateral aspect of the thigh, knee and leg. The lateral aspect of the upper part of the tibia was exposed by mobilisation of the common peroneal nerve, division of the fibula and retraction upwards with the biceps, and mobilisation of the muscles of the anterior compartment of the leg. The lateral condyle of the tibia was removed together with the contained tumour, the lateral semilunar cartilage being left in place (Fig. 8). The defect was filled with a cadaveric graft held in place by two screws. The tibial tubercles were held in place with two Delitala pins. The fibula was replaced and secured with a medullary nail and by fixation to the graft, and the wound was closed (Fig. 9). The limb was immobilised in a plaster.

The plaster was changed ten weeks after operation and was finally removed three months later. One year after operation the patient was walking without difficulty and needed no stick. The range of movement of the knee was full. Six weeks later she began to get pain after much walking or standing, and over the next three months pain, swelling and effusion all increased. In particular, there was tenderness and swelling over the medial aspect of the joint.

A second operation was done at that stage: all the metal was removed and the joint was opened. Some granulation tissue was removed, together with some purulent material. There was much fluid in the joint, containing white flakes. The semilunar cartilage was intact, but the surface of the articular cartilage was rough. The wound was closed and a plaster was applied. The plaster was kept on for six weeks, after which the joint was again mobilised. Two years after operation the patient had no pain in the knee and there was no restriction of movement. Radiographs showed good incorporation of the graft (Fig. 10).
Case 2—Giant-cell tumour of the lateral tibial condyle. Figure 3—Before operation. Figure 4—Appearance after resection of the tumour-bearing bone. Note the osteotomy of the fibula.

Case 2. Figure 5—The homograft inserted and fixed in position. Figure 6—Five years after operation. There has been some collapse and downward displacement of the graft.
Case 3—Giant-cell tumour of the lateral tibial condyle. Figure 7—Before operation. Figure 8—Appearance after resection of the tumour-bearing bone.

Case 3. Figure 9—One year after operation. Good maintenance of position of graft and no collapse. Figure 10—Two years after operation, and after removal of metal fixation. Good union of homograft to tibia, and no collapse of graft.
Case 4—A man aged nineteen was admitted in November 1960 with pain in the medial side of the right knee coming on one month after injury. There was a tender swelling over the medial tibial condyle, and flexion of the joint was limited by pain. Radiographs showed an osteolytic lesion in the medial tibial condyle (Fig. 11). Needle biopsy confirmed the diagnosis of giant-cell tumour.

*Fig. 11*

Case 4—Giant-cell tumour of the medial tibial condyle. Figure 11—Before operation. Figure 12—Appearance after resection. Figure 13—The homograft fixed in place.

*Operation*—A month after admission the tumour was removed through a long incision on the medial side of the thigh, knee and leg. The entire medial tibial condyle was dissected free and removed together with the medial tibial tubercle, after detachment of the patellar and anterior cruciate ligaments (Fig. 12). The defect was repaired with a cadaveric lateral tibial condyle—a medial condyle was not available—held in place by a bolt and wire (Fig. 13). The patellar and cruciate ligaments were attached to the graft, and the medial semilunar cartilage was also sewn back. The wound was closed and a plaster spica was applied.

***Vol. 48 B, No. 4, November 1966***
Nine months after operation there was some instability of the knee and radiographs showed evidence of absorption of the graft (Fig. 14). One year after operation it was clear that absorption had been progressive and that further operation was required. At that stage osteotomy of the tibia and fibula was done, the bolt was removed and a Steinmann pin was inserted into its track in order to elevate the depressed graft. Four months after the second operation the tibial fragments were united and the knee had a range of movement of 90 degrees. There was some lateral instability of the joint, but function was good. Radiographs showed that incorporation of the graft had been inadequate and that its position had not been maintained (Fig. 15).

![Fig. 14](image1)

**Fig. 14**
Case 4. Figure 14—Nine months after operation. There has been collapse and displacement of the graft. Figure 15—Three years after first operation, and twenty months after osteotomy. Collapse and absorption of the graft.

**Case 5**—A woman aged fifty-six was admitted in December 1962 with pain in the left knee after injury. There was swelling and limitation of movement, and tenderness over the lateral femoral condyle. Radiographs showed an osteolytic lesion in the lateral femoral condyle (Fig. 16). Needle biopsy confirmed the diagnosis of giant-cell tumour.

**Operation**—A long lateral incision was made and the joint was opened. The articular surface was found to have collapsed. After division of the fibular collateral and cruciate ligaments the lateral femoral condyle containing the tumour was removed (Fig. 17) and was replaced by a cadaveric graft fixed in place with two screws (Fig. 18). The ligaments were attached to the graft and the wound was closed. A plaster spica was applied.

The plaster was removed six weeks after operation and active movements of the knee were begun. Eleven months after operation the patient began to walk without crutches, and six months later the knee had good function, though there was slight lateral instability and some restriction of flexion. Radiographs showed that there had been some absorption of the graft (Fig. 19).

**Case 6**—A woman aged thirty-eight was admitted in June 1957 with weakness of the left knee following injury eight months previously. The muscles of the thigh were wasted, and the femoral shaft was enlarged. Radiographs showed an osteolytic lesion in the middle of the femoral shaft, and areas of osteolysis in the medullary cavity of the lowest third of the femur (Fig. 20). Needle biopsy was done, and whitish membranes resembling hydatid cysts were aspirated. A provisional diagnosis of hydatid disease was made.

**Operation**—A postero-lateral incision was made from the hip to the knee and the vastus lateralis muscle was detached. A large abscess was found in the lowest third of the femur, spreading into the
Case 5—Giant-cell tumour of the lateral femoral condyle. Figure 16—Before operation. Figure 17—Appearance after resection.

Case 5. Figure 18—The graft two months after operation. Figure 19—One year after operation. There has been some absorption of the medial part of the graft.
Case 6—Hydatid disease of the femur.

Figure 20—Before operation.
Figure 21—The upper part of the homograft soon after operation.

Case 6—Sixteen months after operation. Trochanteric fracture and evidence of necrosis of head of femur.

Figures 23 and 24—Seven years after operation. Non-union of the trochanteric fracture and necrosis of the femoral head, but sound fusion of the arthrodesis of the knee.
popliteal fossa. The uppermost third of the femur was found when cut through to be affected with hydatid disease. Accordingly the whole femur was removed after disarticulation at the hip and at the knee. It was replaced with a femur removed from a cadaver three weeks previously. Several holes were drilled in this graft in order to assist revascularisation. Arthrodesis of the new knee was done, and the head of the femur was held in place by two Steinmann pins transfixing it and entering the acetabulum (Fig. 21). The muscles were closed around the graft and a plaster spica was applied.

Sections through the resected femur showed that the whole medullary canal was affected by hydatid disease (Fig. 25).

The wound healed well, and progress was good. In October 1957 the pins were removed from the hip, and the opportunity was taken to do a needle biopsy at the same time. The femur appeared to be softer than a normal one. The plaster was kept on for another two years, during which period there was a fracture through the base of the femoral neck, followed by progressive coxa vara (Fig. 22). Later, there was necrosis of the head and neck of the grafted femur. After removal of the plaster the patient began to walk with a stick, and eventually, seven years after operation, she was able to walk easily with a stick. The knee became firmly fixed and there was only one inch of shortening. There was no pain. Radiographs showed non-union of the fracture of the femoral neck, with necrosis of the femoral head, but the appearance of the shaft was excellent (Figs. 23 and 24).

Case 7—A man of twenty-three was admitted in September 1959 with pain in the right shoulder and arm. He had previously had a biopsy done on a lesion in the upper part of the humerus. Radiographs showed a lesion in the uppermost third of the humerus, with some condensation of the cortex and with some osteolytic areas (Fig. 26). Operation was done in October 1959.

Operation—Henry's (1957) incision was used to expose the shaft of the humerus. The head of the humerus was disarticulated, the soft tissues were separated from the bone, and the upper two-thirds of the bone was removed. It was replaced with a cadaveric graft, secured below with two bolts and attached above with stitches to the capsule of the shoulder joint and to the rotator cuff (Fig. 27). The wound was closed and the limb was put into a plaster spica.

Examination of the resected tumour confirmed the diagnosis of chondrosarcoma (Fig. 28).

The plaster was kept on for some months. Ten months after operation there was seen to be a fracture through the neck of the humerus. A "hanging cast" was applied. Three weeks later the patient broke the graft again while riding a motor-cycle; this time the fracture was through the shaft (Fig. 29). A plaster spica was applied. By May 1961 the fracture through the shaft of the graft was consolidated, but there was non-union of the fracture through the neck of the bone (Fig. 30). A second operation was done: a tibial graft was applied at the level of non-union and the rest of the graft was inspected. The bone looked normal and bled normally; the marrow was yellowish and appeared necrotic. Histological examination showed that the graft was partly necrotic and was about to be reabsorbed. There was no evidence of recurrence of tumour.

By September 1961 the fracture had consolidated and there was good evidence of incorporation, though there was some absorption in the lateral part of the humeral head. Four and a half years after operation the patient has good function of the arm and can use a typewriter and ride a motor-cycle. Radiographs show good incorporation of the graft and union of both fractures, though there is collapse of the articular surface of the humerus (Fig. 31).

DISCUSSION

The idea of transplanting whole joints is not new. It was probably Tuffier (1901) who made the first attempt; he was followed by Judet (1908), Impallomeni (1911) and Dalla Vedova (1911). In 1913 Pucci transplanted an elbow joint with a good result. Wrede (1909), Ducuing
Case 7—Chondrosarcoma of the humerus. Figure 26—Before operation. Figure 27—After resection and homograft replacement. Figure 28—The resected bone, showing the central chondrosarcoma. Figure 29—One year after operation. Fractures through the neck and shaft of the grafted humerus. Note the callus around the lower fracture. Figure 30—Six months later. The lower fracture is healed, but there is non-union of the upper one. Figure 31—Four and a half years after operation. Shaft of graft in good condition; partial absorption of the head of the humerus with degenerative changes in the shoulder joint.
(1912) and Minoura (1914) did some experimental work on animals. Lexer (1907) was the first to use massive grafts of bone and joint taken from the living patients and transplanted immediately after removal. By 1925 he had done twenty-three such operations, and was able to assess the late results in twelve cases—nine of transplant of the knee joint and three of transplant of a finger joint. In several of his cases of transplant of half the knee there was an excellent functional result six to ten years after operation, in spite of radiological evidence of degeneration of bone and joint. Bürkle de la Camp (1929) examined two of Lexer's patients fourteen and sixteen years respectively after operation and found the same.

The recent work of Herndon and Chase (1952) has advanced our knowledge of this subject. They studied the behaviour of autogenous and of homogenous grafts in dogs, and obtained uniformly good results with the former. Revascularisation began early and was complete in nine months, though there was regularly degeneration of articular cartilage in areas of increased pressure and replacement by fibrocartilage. Both fresh and frozen homografts behaved like the autografts during the first four to six months, but after that necrosis was more intense and articular cartilage was absorbed and not replaced, so that microfractures of the underlying bone occurred.

THE PRESENT SERIES

The fate of the bone—These large homografts at first underwent necrosis and later were revascularised, principally from the area of contact with healthy bone. The parts of the graft most remote from contact from living tissue are the last to be replaced. Although it is usual for the radiological appearances of the diaphysis of the graft to suggest that its incorporation is better than that of the epiphysis, this suggestion is not borne out by histological examination. The decalcification of the epiphysis shown in the radiograph is seen to be the result of revascularisation. In one case—that of a massive replacement for chondrosarcoma of the humerus—the graft became available for examination eight months after operation. Radiographs showed excellent union between the lower end of the graft and the healthy bone. Histologically, the upper end of the graft showed the better evidence of incorporation; there were many areas of necrosis in the cortex of the shaft. The articular cartilage of the head of the humerus was necrotic and ulcerated, the processes of necrosis prevailing over those of regeneration (Figs. 32 to 35).

The fate of the joint—It is certain that the function of the reconstructed joint can be excellent even though the radiograph shows absorption of the graft and collapse of its articular surface. The changes in these joints are rather like those seen in neuropathic conditions, and it may be that the lack of innervation is responsible for some of them.

Judet (1908) showed that nutrition of articular cartilage was provided by the synovial fluid; Scaglietti and Casuccio showed that the stimuli of normal function were necessary to preserve its integrity. The immobilisation necessary after massive transplant may thus favour degeneration and necrosis of cartilage, though obviously it helps to avoid collapse of the subchondral bone.

Functional results in the present series—In all five cases of giant-cell tumour the movement of the affected joint was preserved. It was best in the case of affection of the ulna, doubtless because the elbow joint is not subjected to heavy stress and strain. In one case of replacement of the lateral tibial condyle the graft collapsed, possibly because the patient walked before the fifth month, against advice. The functional result, however, was excellent. In the other case there was no collapse, even though a second operation for a sterile abscess was necessary. That operation revealed necrosis of the articular cartilage, but there was evidence of revascularisation of the bone of the graft. Transplant was done in two other knees: in one of these cases—that of replacement of the lateral femoral condyle—it is too soon after operation to assess the result. In the other case—that of replacement of the medial tibial condyle—there was marked absorption and collapse of the transplant, but the functional result was good.
Histological changes in homograft replacement of the upper part of the humerus. Figure 32—Articular cartilage and subchondral bone. There is degeneration of the articular cartilage. The bone is necrotic in parts (a), and in other parts shows evidence of revitalisation with thickened trabeculae (b, b). Figure 33—Higher magnification. Necrosis of articular cartilage and revitalisation of subchondral bone. (c) Some necrotic bone trabeculae surrounded by neoformative bone and well vascularised connective tissue are observed. Figure 34—Necrotic trabeculae (d, d) surrounded by new bone and by vascular connective tissue. Figure 35—A necrotic trabecula (e) at high magnification, surrounded by connective tissue and new bone.
Operation in the case of hydatid disease of the femur was done over six years ago. The result was very satisfactory, both from the point of view of cure of the disease and from that of functional result. In this case the knee joint was arthrodesed, but the mobility of the hip remains fully adequate in spite of some necrosis and collapse.

The functional result in the case of replacement of the humerus for chondrosarcoma was very good. The graft broke twice and its shaft healed like that of a healthy bone.

**General comment**—The results in the present series certainly do not support the rather pessimistic opinions of Vigliani (1958), who did not think that there was a place for such operations. Progress in the present cases was like that in Lexer's and similar to that seen in Chase and Herndon's experimental studies. The first signs of absorption of bone and necrosis of cartilage appeared after several months of normal clinical and radiographic findings. Later on, however, there seemed to be a progressive improvement in the radiographic appearances.

It would be worth while to investigate the histological evolution in such cases in order to find out, in particular, whether after necrosis of cartilage has occurred the revascularisation of subchondral bone may help to produce fibrocartilaginous regeneration. It would also be useful to know whether it is better to preserve the articular cartilage of the graft or to peel it off and insert a sheet of fascia, as was done in Case 2.

**SUMMARY**

1. Seven cases of massive osteoarticular transplant for conditions affecting major joints are described. In one case the whole femur was replaced.
2. The transplants were well accepted, though there was a varying degree of absorption of bone and necrosis of articular cartilage.
3. The functional results were very satisfactory, and movements of joints were well preserved.
4. In these cases recurrence of the original disease was not seen.
5. Such operations are still in an experimental stage, but they are likely to have a permanent place in treatment in certain carefully selected cases.

**REFERENCES**


