Resection-Arthrodesis for Malignant and Potentially Malignant Lesions about the Knee Using an Intramedullary Rod and Local Bone Grafts*

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ABSTRACT: **Twenty patients with malignant or potentially malignant tumors (osteogenic sarcoma, giant-cell tumor, synovial-cell sarcoma, chondrosarcoma, and chondroblastoma) located in the proximal end of the tibia or distal end of the femur were treated by local resection and arthrodesis employing an intramedullary rod and autogenous segmental cortical grafts obtained from the same extremity. Use of a customized bent, fluted rod in the most recent cases provided more stable fixation. There was only one local recurrence. In properly selected patients, the method provided a stable extremity that permitted resumption of a vigorous life-style within approximately one year.**

Certain potentially malignant and low-grade malignant tumors about the knee, such as aggressive giant-cell tumor, chondrosarcoma, recurrent chondroblastoma, and carefully selected higher-grade malignant lesions, may be satisfactorily controlled by adequate local resection of the lesion [3,4,12,13,17,20,21,23,27,29-32,37]. Reconstruction of the defect created by such resection may be accomplished in a variety of ways, including shortening the extremity and arthrodesis, arthrodesis with large spanning bone grafts to preserve length, arthroplasty utilizing custom-made prosthetic replacements, and homotransplanted half-joints [12,15,16,19-21,25-29,35,36,38,39].

Local resection and arthrodesis for tumors about the knee was first described in 1907 by Lexer [15,16] and subsequently by others [13,20,21,29,39]. These and other authors noted that they were relatively successful in controlling the tumor, but that frequent complications — including infection, non-union, and late fatigue fracture — made rehabilitation long and difficult. Drawing on this previous experience, we evolved a method that has to date given satisfactory tumor control and improved rehabilitation within the limitations of a knee arthrodesis (Figs. 1-A and 1-B).

Materials and Methods

Preoperative Assessment and Patient Selection

Patients were selected for this procedure who had biopsy-proved lesions of the distal end of the femur or proximal end of the tibia that either were known to have unacceptably high recurrence rates after procedures of lesser magnitude (chondrosarcoma, osteosarcoma, aggressive giant-cell tumor) or had recurred one or more times in the past after more conservative procedures (chondroblastoma, giant-cell tumor, and the like) [3-5,10,17,30,34]. The lesions selected for this treatment also had to involve the epiphyseal region of the femur or tibia in such a way that adequate resection with preservation of joint function was not possible.

If these criteria were met, the next step was to establish that there was an adequate plane for surgical dissection between the tumor and the adjacent neurovascular structures so that they could be preserved without violating the tumor; in other words, that frankly malignant lesions were entirely intra-osseous while the potentially malignant ones were so placed that at least one plane of normal tissue lay between them and the neurovascular structures [6,33].

The intra-osseous proximal and distal extent of the lesion was carefully considered. An adequate diaphyseal margin was taken to be a plane of section at least four centimeters away from the intramedullary or cortical margin of the lesion as shown by tomography and a bone scan. If the cartilage was intact, a through-the-joint resection and intracapsular dissection was performed. If there was joint invasion or fracture extending from the lesion into the joint cavity, an extra-articular resection with extracapsular *en bloc* excision of the opposing articular surface and subchondral bone was performed. For the postresection stabilization to be satisfactory, no more than the distal one-third of the femur or the proximal one-third of the tibia could be removed.

To make these assessments required a combination of studies, including adequate roentgenograms and tomograms (intra-osseous extent), radio-scans (roentgenographically occult intramedullary extension), biplane angiograms (soft-tissue extent and relationship to neurovascular structures), arthrograms (intra-articular extent), and other special studies that might yield additional pertinent data. Since the findings by all of these studies are to some extent obscured by the tissue response to either fracture or biopsy, they were performed prior to biopsy when the clinical picture strongly suggested that resection would be feasible. If the patient had a pathological fracture through

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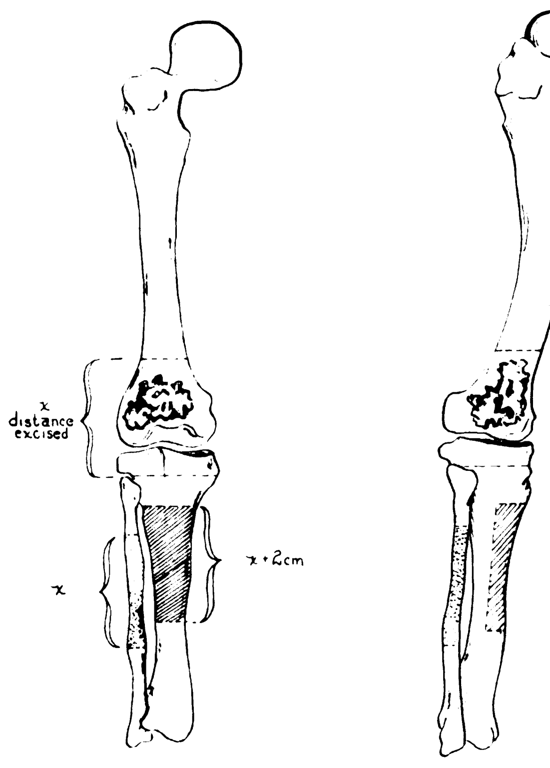

FIG. 1-A

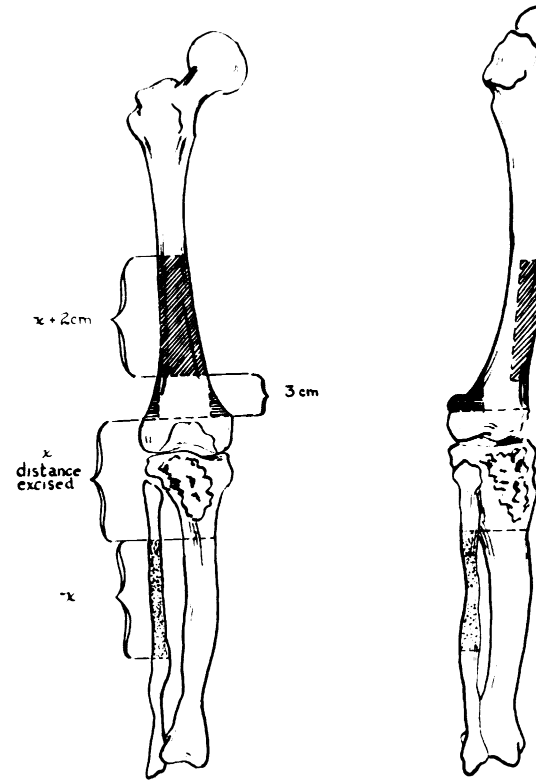

FIG. 1-B

Tibial lesion.

Figs. 1-A and 1-B: General plan for resection-arthrodesis of femoral and tibial lesions, showing resection sites (broken lines) and grafts (cross-hatched areas).

Fig. 1-A: Femoral lesion.

or into a lesion likely to be resectable, healing of the fracture was allowed to occur before the studies were done. However, the risk of soft-tissue extension of a frankly malignant tumor had to be weighed in making this decision.

All patients seen during the seventeen years covered by this study who had lesions that were located about the knee which were considered resectable were offered arthrodesis. Those with low-grade malignant or potentially malignant lesions for which other alternatives could be considered (amputation, prosthesis, homotransplant, or cryosurgery) were, in some instances, reluctant to accept fusion; all of those with frankly malignant lesions, for whom the alternative was hip disarticulation, showed no hesitation in accepting arthrodesis. The majority of patients who accepted resection-arthrodesis did so even though we suggested referral to other centers where alternative procedures with which we had had no experience could be performed. The decision to perform resection-arthrodesis was based on the surgeon's bias, financial considerations, consultation obtained independently by the patient, and other factors. During the time covered by this study, an almost equal number of patients who met the described criteria preferred and received above-the-knee amputation, for a variety of reasons. In all, thirty-two patients were treated in the way to be described. This report concerns the first twenty patients who were followed either until they died of the disease or for periods ranging from one to fourteen years. If resection-arthrodesis was elected, carefully "scaled" anteroposterior and lateral roentgenograms were made on ninety-one-centimeter film to determine the lengths of the femur and tibia, the diameter of the medullary canal at the isthmus of both the tibia and the femur, and the degree of curvature of the femur in the anteroposterior plane (lateral view). From these roentgenograms, in the latter part of this study, the necessary measurements were obtained to permit fabrication of the customized intramedullary rod now used; to facilitate planning of the grafts; and to aid in determination of both the amount of bone to be resected and the lengths of the temporary spacers needed (Figs. 2-A and 2-B).

Operative Technique

Special Devices

Initially, a straight Küntscher or Street rod of the appropriate length was used, but neither one was satisfactory because there was a loose fit of the rod in the femur, with rotatory instability; the rod was relatively flexible, necessitating prolonged external support postoperatively; and there was relative hyperextension at the fusion site due to the absence of the distal end of the femur, as well as loss of three-point fixation of the loose-fitting nail in the femur. Therefore, based on a study of the femur in adolescents and adults of varying age, size, and sex, a fluted intramedullary rod was designed and fabricated. Its proximal half had a radius of curvature of either 125 or 175 centimeters to fit the femur, while its distal half was

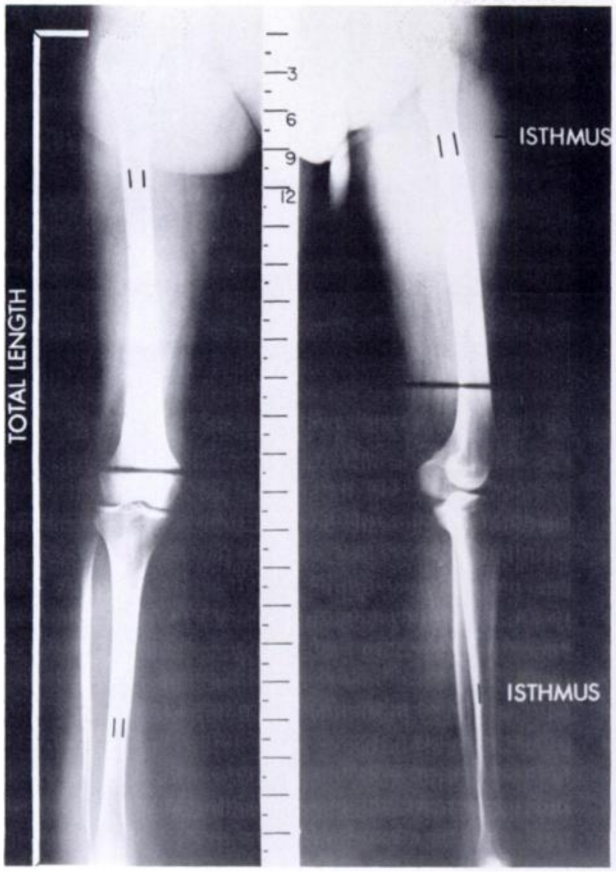

FIG. 2-A

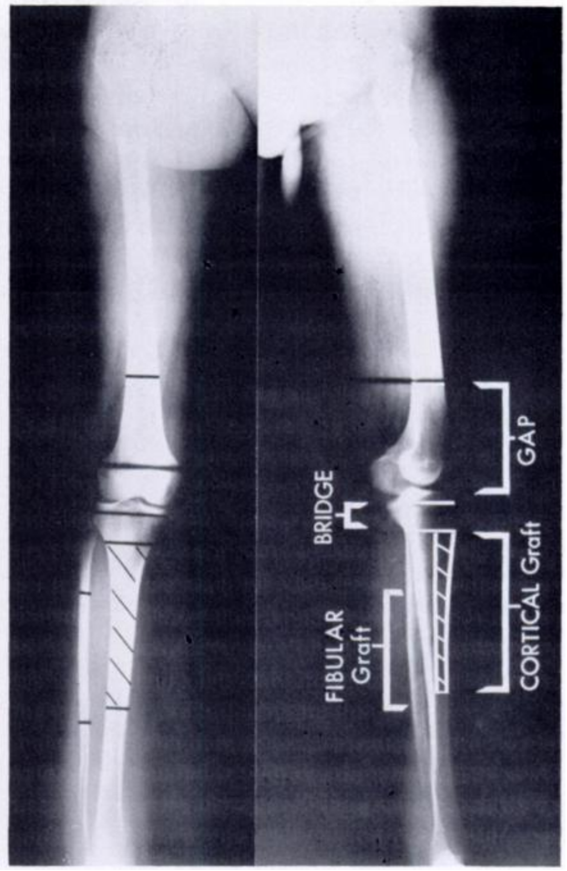

FIG. 2-B

Figs. 2-A and 2-B: Preoperative roentgenograms used to plan the operative procedure.
Fig. 2-A: Determination of length and diameter of nail.
Fig. 2-B: Determination of length of the resected segment and approximate size and location of grafts.

straight to fit the tibia. The curve permitted retrograde insertion in the femur, and once in final position the rod fixed the extremity with 5 to 10 degrees of flexion at the site of the knee. The fixation provided by this device was compared with that provided by a Küntscher rod by biomechanical testing of the lower extremities of cadavera after performing the resection-fusion procedure using a conventional straight Küntscher rod on one side and the semicurved, fluted rod on the other. The two configurations were of equal strength in compressive loading and failed at loads of ninety kilograms at the junction of the anterior graft with the bridge of metaphyseal bone preserved on the femur or tibia [22].

This semicurved, fluted rod was used in four of the last five patients in this series and in an additional eleven patients whose cases were not included in this report because follow-up was less than one year. Each of these rods was fabricated so that its root diameter was equal to that of the isthmus of the tibia; its radius of curvature was either 125 or 175 centimeters to accommodate the different amounts of bowing of the femur; and its length provided for one centimeter of over-all shortening of the extremity compared with the opposite limb.

The amount of bone to be resected was carefully determined from the preoperative roentgenograms. Rectangular aluminum blocks, measuring three by five centimeters in cross section and increasing in length by 0.5-centimeter increments from three centimeters less to three centimeters more than the anticipated amount of bone to be resected, were sterilized with the operative instruments.

Surgical Procedure

If there has been no previous biopsy, a straight, anterior midline incision over the area to be biopsied is made down to bone, a cortical window is created, and a specimen is obtained for frozen section. The window is then completely sealed with methylmethacrylate, every effort being made to avoid contamination of the wound with lesional tissue. The biopsy wound is closed and sealed with skin cement and adhesive plastic drape; it is excised *en bloc* at the time of the definitive procedure. If this second procedure is done at the same sitting, all instruments, drapes, gowns, gloves, and other potentially tumor-contaminated materials are discarded, and the procedure is performed after redraping, using new instruments. At this procedure, a straight, anterior midline incision is made from the junction of the proximal and middle thirds of the thigh distally to the junction of the distal and middle thirds of the leg (Fig. 3-A). If previous incisional biopsy scars are present and they can be safely excised in this incision without impairing the blood supply to the flaps, they are so managed. The margin about these scars should be at least one centimeter in all dimensions and the soft tissues beneath the scar should be incised sharply down to bone, so that all of the previously potentially contaminated tissue is removed *en bloc* with the lesion. If the previous scar or scars are lateral, posterior, or medial, they are circumscribed by separate elliptical incisions and removed *en bloc* and in continuity with the lesion. During this dissection, the knee is flexed 90 degrees and medial and lateral flaps of skin and subcutaneous tissues are developed so that the distal third of the femur, the proximal third of the tibia, and the popliteal fossa can be easily visualized both medially and laterally (Fig. 3-B).

If the resection is to be through the joint, the patellar tendon is divided, the joint capsule and ligaments are sectioned along the joint line, and the patella and quadriceps are reflected proximally as a unit. If there is any question as to the presence of intra-articular involvement, a parapatellar incision is made and the joint is inspected. If the lesion is visible within the joint, the capsulorrhaphy site is meticulously closed and an extracapsular dissection is performed. Similarly, if there is known joint-cavity contamination by direct extension, prior intra-articular biopsy, or a communicating fracture, an extra-articular resection is necessary.

If resection through the joint is possible, the cruciate ligaments are divided to permit distraction of the joint surfaces. The distal end of the femur or the proximal end of the tibia containing the lesion is then dissected free, preserving an adequate envelope of normal tissue about the lesion; in other words, the dissection is made one anatomical plane beyond the most peripheral tissue involved by the lesion [33]. The dissection along either bone is carried three centimeters beyond the preselected plane of resection. The neurovascular bundle is retracted posteriorly and any branches are ligated as necessary. If the proximal end of the fibula is to be removed *en bloc* with the tibia because of soft-tissue involvement in the interval between the tibia and the fibula, the anterior tibial vessels are divided and the peroneal nerve is retracted. The bones are then divided at the appropriate level; frozen sections are obtained from the medullary canals of the remaining bone segments to assure a safe level of resection; and the specimen is bisected and inspected. If there is any question of involvement of a margin of the specimen at any point, the tissue that was adjacent to this point in *situ* is biopsied.

If an extra-articular resection is to be done, the dissection is carried out so that the joint capsule is not violated. The overlying soft tissues are carefully resected from the capsule, the neurovascular structures are retracted, appropriate resection of the tumor is done, and the portion of the uninvolved bone (tibia or femur) to be resected is removed *en bloc* with the joint after dividing it just beyond the line of attachment of the capsule.

Following the resection and verification of its ade-

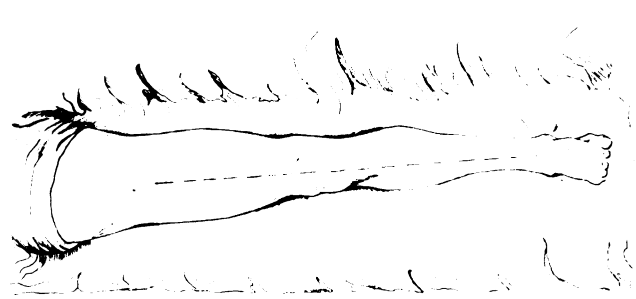

FIG. 3-A

FIG. 3-B

Figs. 3-A and 3-B: Exposure required for resection-arthrodesis.
Fig. 3-A: Midline incision.
Fig. 3-B: Development of flaps.

quacy, the tourniquet is removed and hemostasis is obtained. If the resection is through the joint, the articular cartilage of the uninvolved bone together with one centimeter of the subchondral bone is removed by making a transverse cut. A spacer bar whose length is the same as that of the gap is used as a guide in the removal of a bone graft of the same length from the mid-shaft of the fibula. The distal end of the fibular segment is then beveled for a distance of one centimeter from the cut surface and a snug-fitting Steinmann pin or Kirschner wire is passed through the medullary canal of the graft to protrude one centimeter beyond the opposite, transversely cut end. A hole of the same diameter as the pin is then drilled longitudinally one centimeter into the posterior cortex of the remaining portion of the bone from which the lesion is resected. The portion of the pin protruding from the opposite beveled end of the graft is cut off one centimeter beyond the segment and bent back along the beveled surface to prevent pin migration. Before inserting the fibular graft, the medullary canals of the femur and tibia are reamed with flexible reamers. Since the flutes extend two millimeters beyond the root diameter of the nail, the tibial and femoral canals are reamed to a diameter one millimeter in excess of that of the barrel. This over-reaming prevents distraction as the nail is driven in but does not compromise rotatory stability. In the femur, flexible reamers are required to accommodate the curve. When beginning the reaming of the bone on the unresected side of the joint, care must be exercised to begin in line with the medullary canal, so that a large cavity is not left around the nail where it emerges from the cancellous bone in this region.

The rod, with a removable perforating tip attached, is now driven proximally up the femoral canal and out through the skin of the buttock. The curve of the rod must match the anterolateral bow of the femur, and the rod must be driven proximally until the segment projecting beyond the distal end of the femur is equivalent to the length of the resection gap minus one centimeter (Figs. 4-A and 5-A).

A cone-shaped depression that will accommodate the beveled end of the fibular graft is then made with a curette in the cancellous bone of the tibial or femoral metaphysis just posterior to the previously prepared tract for the rod. The transversely cut end of the fibular graft is placed against the posterior cortex of the femoral or tibial segment, where it is held in place by the protruding Steinmann pin. When the fibular graft, which is one centimeter longer than the gap, is being seated, considerable tension must be placed on the neurovascular structures and may produce a transient peroneal-nerve palsy. The leg is aligned with the thigh to receive the rod. The rod is then driven distally two or three centimeters while the beveled end of the fibula is held in the previously curetted depression. After the alignment is checked, a spacer bar one centimeter shorter than the gap is placed anterior to the rod and the leg is manually impaled on the rod, thereby driving the beveled end of the fibular graft into the cancellous bed. The spacer bar prevents excessive shortening of the gap as the rod is driven into the tibia. Prior to seating the fibular graft, it should be adjusted so that its concave aspect matches the posterior arc of the rod. The sole of the foot is firmly supported against the abdomen of an assistant as the rod is slowly driven distally (Figs. 4-A and 5-A). As the rod approaches the isthmus of the tibia, distraction of the gap is prevented by proximal pressure, forcing the tibia against the spacer bar. When the rod is seated, there should be no motion in the assembly during rotation, bending, or distraction-compression.

The donor site of the anterior graft is then exposed on the anterior surface of the tibia or femur. The exposure should extend from the plane of resection and along the metaphysis, either proximally on the femur or distally on the tibia, for a distance that is five centimeters more than the length of the gap. Since the graft is composed of the anterior half of either the femur or the tibia, medial and lateral cuts are made, aiming the saw at the central axis of the rod. Transverse cuts are made at the proximal and distal ends of the graft, the transverse cut nearest the resection site being made three centimeters from the plane of resection to preserve an anterior bridge of bone to prevent angulation of the tibia or femur on the rod (so-called bowstringing). The other transverse cut is made at a distance from the first one equivalent to two centimeters more than the length of the gap. When the graft is removed, its undersurface should include the trough created by the rod (Figs. 4-B and 5-B). The narrow end of the graft is now beveled, the plane of the bevel being at 45 degrees and the apex of the bevel, at the endosteal surface of the cortex. The graft is reversed end-for-end and placed so that it bridges the gap, with the beveled end abutting against the anterior cortex of the bone from which the graft was not taken. It must be aligned so that the trough on its endosteal surface is in line with the underlying rod and the wider cancellous end overlaps the bridge on the bone from which the graft was removed by from 1.5 to two centimeters. A beveled slot about 0.5 centimeter deep is cut in the anterior cortex of the bone (femur or tibia) that is to receive the beveled narrow end of the graft, to prevent displacement. With the graft wedged in place, the outline of the overlapping part of the graft at the other end is marked carefully on the underlying bridge. The graft is then set aside and the bone within the marked area on the bridge is removed to a depth that will allow the graft to be countersunk into the bridge, so that their surfaces are flush. Once the fit of the graft in its bed is satisfactory, the graft is again set aside and the flares of the femoral condyles and tibial plateaus are trimmed so that they project only two centimeters medially, laterally, and posteriorly around both of the grafts. This trimming eliminates subsequent troublesome, sharp subcutaneous protrusions and provides cancellous bone for supplementary grafting at the potential sites of non-union.

To secure the anterior graft, the beveled edge is driven into place, the wide end is placed in its bed in the bridge, and the leg is pushed proximally a few millimeters to force the beveled ends of both grafts firmly into their slots. Should there be any instability of the beveled ends, a figure-of-eight wire or a single screw can be used for additional fixation. Both grafts should then be stable when the leg is gently manipulated.

If the patella and quadriceps mechanism have been preserved (resection through the joint), they are now laid in place so that the patella rests over the junction of the anterior graft and the bridge. This is accomplished easily if a tibial lesion was resected and the junction is proximal to the original joint line. Lengthening of the quadriceps tendon may be necessary if a femoral lesion was resected. The articular cartilage of the patella is removed to fashion a broad surface of cancellous bone. The patella is then fixed in position by a large Steinmann pin, drilled from anterior to posterior, either medial or lateral to the rod and so placed that it transfixes the patella, graft, and underlying bed. A hole is then drilled on the other side of the rod to receive a cancellous-bone screw, overdrilling the hole in the patella so that the screw will compress the patella against the graft and prevent anterior dislodgment of the graft. Once this screw is in place, the Steinmann pin is removed and a second screw is inserted where the pin was before. Additional screws as needed for firm fixation may be used to secure the graft in its bed (Figs. 4-C and 5-C). If an extra-articular resection was done and the patella and quadriceps mechanism were resected, two cancellous screws, on each side of the rod, are used to secure the graft into its bed in the bridge.

The excised portions of cancellous bone are now carefully packed about the four junctions of the grafts with

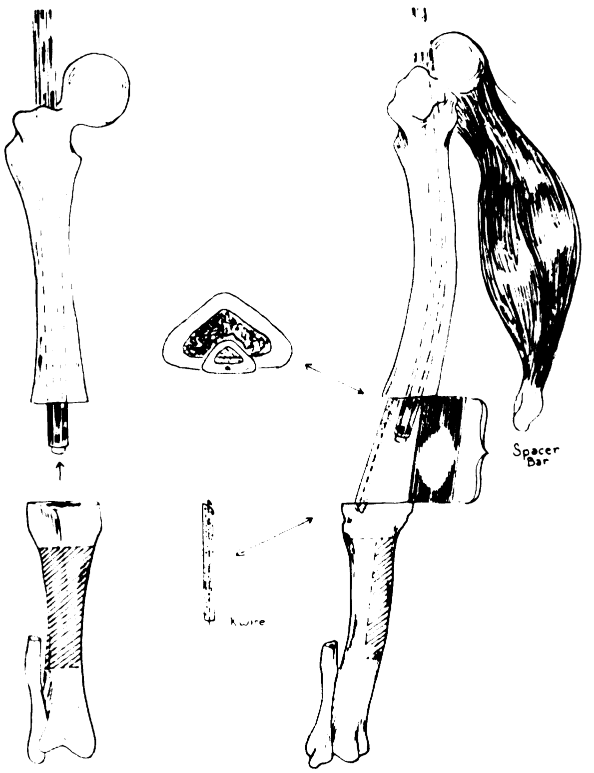

FIG. 4-A

Figs. 4-A, 4-B, and 4-C: Technique for arthrodesis after resection of a femoral lesion.

Fig. 4-A: The rod has been inserted retrograde into the femur; the posterior fibular graft with the intramedullary pin in place is advanced one centimeter into the cancellous bone of the tibia, and a spacer block is inserted prior to driving the rod down the tibia.

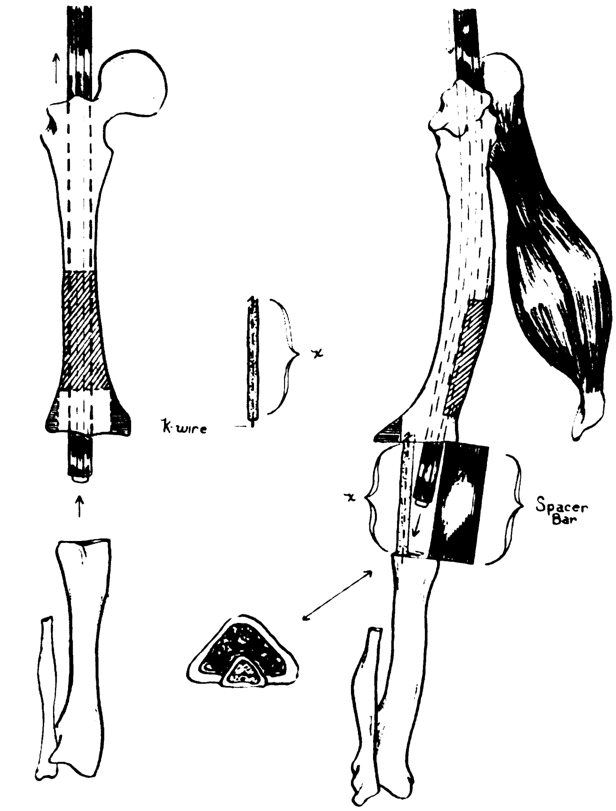

FIG. 4-B

The rod is in place and the tibial cortical graft has been removed, leaving the tibial metaphyseal bridge.

the host bones. Priority is given to the junctions between the fibular graft and the femur and tibia and between the beveled end of the anterior graft and the femur or tibia, since experience has shown that these are the most likely sites of non-union.

The wound is closed in layers, with care taken to protect the neurovascular structures from direct contact with bone. Potential dead space is decompressed by inserting suction tubes. All sharp protrusions of bone are smoothed to prevent concentration of pressure on the overlying skin and subcutaneous tissues. The limb is then encased in a toe-to-groin modified Jones dressing.

The only important variation in technique was in the two patients in whom just the proximal end of the tibia was resected. In these instances, after the rod was in place the projecting proximal end of the fibula was placed against the lateral femoral condyle and secured there with a Steinmann pin, rather than using a free posterior fibular segmental graft as described.

An ancillary procedure, carried out in twelve patients, was to obtain a separate two-centimeter segment of the fibula and place it near the site of the patellar screws. This piece, which played no integral role in the reconstruction, was removed about six months later along with the screws to assess the amount of repair in the grafts and serve as a guide to when weight-bearing could be resumed. Since the amount of repair in these cases proved to

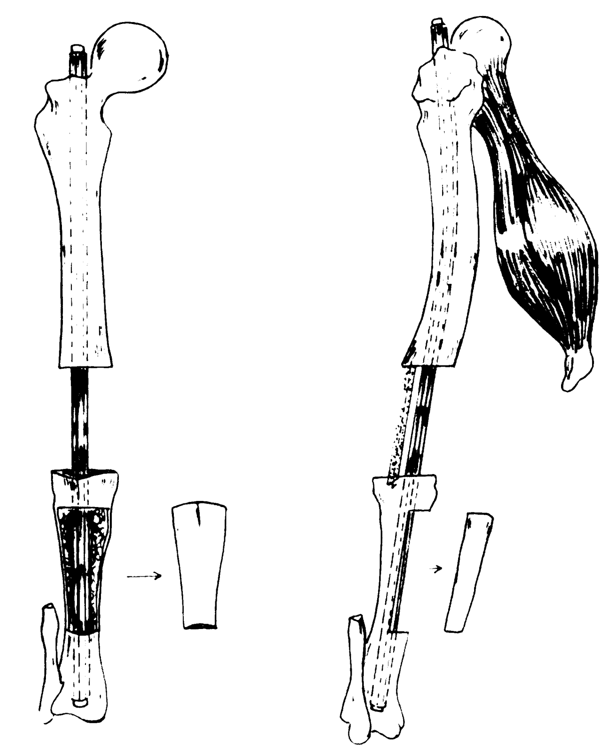

FIG. 4-C

The anterior graft from the tibia is inserted into the slot in the femur proximally, countersunk into the tibial bridge distally, and fixed with two screws. In a through-the-knee resection, the posteriorly decorticated patella is also fixed over the distal end of the graft with two screws.

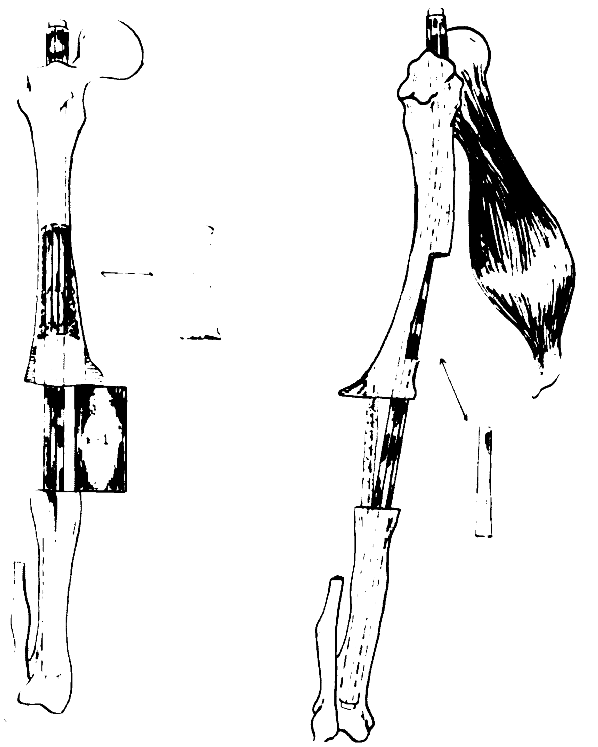

FIG. 5-A

Figs. 5-A, 5-B, and 5-C: Technique for arthrodesis after resection of a tibial lesion.

Fig. 5-A: The rod has been inserted retrograde into the femur; the posterior fibular graft, x centimeters in length (x being the length of the gap), is pushed into the cancellous bone of the femur. A spacer block, x minus one centimeter long, is then placed in the gap and the rod is driven distally down the tibia.

be fairly uniform, the procedure was discontinued.

Postoperative Regimen

If there was demonstrable instability at the conclusion of the procedure, the patient was placed in a one and one-half hip spica and kept recumbent until roentgenograms showed union (Case 10). Otherwise, the limb was kept elevated until the wound or wounds had healed, and then it was placed in a toe-to-groin cast with a quadrilateral socket. The patient then began to walk with crutches and a three-point non-weight-bearing gait. Roentgenograms of the resection site were made prior to application of the plaster cast to establish the position of the grafts and fixation devices. Patients in whom the small additional fibular grafts had been inserted to study healing were begun on 250 milligrams of tetracycline four times a day starting one week postoperatively, in order to label the new bone formed within the repairing grafts. This medication was continued daily until the specimen was removed [7,8].

Two months after operation, roentgenograms were made again to assure that the reconstruction remained stable and if so, the patient continued to walk non-weight-bearing. At four months, if union was visible, a new plaster cast was applied with the foot and ankle free and partial weight-bearing (about 11.3 kilograms) was begun. At six months, if union was solid, as was usually the case, a contour-fitting brace with an ischial seat and a free

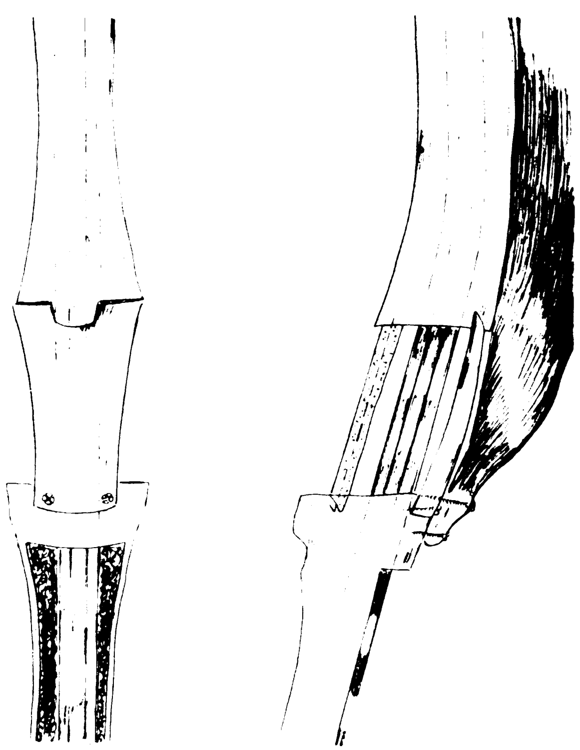

FIG. 5-B

The rod is in place and the femoral cortical graft has been removed, leaving a femoral metaphyseal cortical bridge.

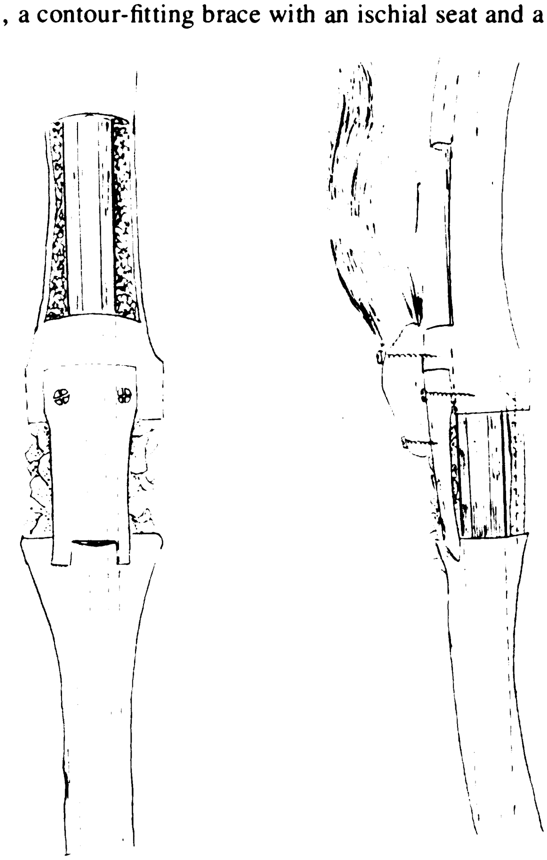

FIG. 5-C

The anterior graft from the femur is inserted into the slot in the tibia distally, countersunk in the femoral bridge proximally, and fixed with two screws. In a through-the-joint resection, the decorticated patella is also fixed over the distal end of the graft with two screws.

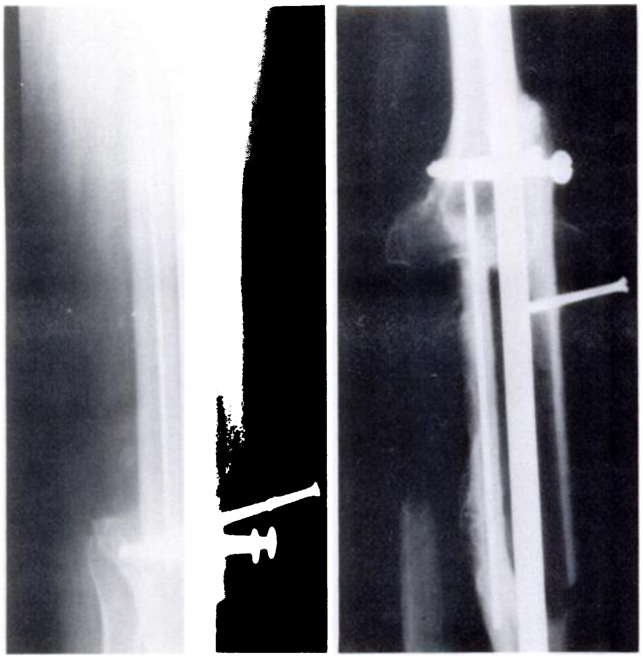

FIG. 6-A FIG. 6-B

Figs. 6-A and 6-B: Examples of solid healing one year after resection-arthrodesis.

Fig. 6-A: Case 18. The grafts are solidly healed; the patient is bearing weight without support one year after resection of a femoral lesion.

Fig. 6-B: Case 13. The fibrous graft is hypertrophied; the patient is bearing full weight one year after resection of a tibial lesion.

ankle was fitted and the patient began to walk with a cane. At one year all external supports were discontinued and full activity was encouraged (Figs. 6-A and 6-B).

Six months after operation, the screws transfixing the patella were removed so that further healing during the next six months would eliminate these points of stress concentration before full activity was resumed. The two-centimeter fibular segments implanted in twelve patients were removed at this time. If any of the four junctions between the grafts and the tibia or femur failed to show conclusive evidence of solid union roentgenographically at six months, the questionable junctions were explored; additional onlay cancellous iliac grafts were applied if a non-union was verified. In the presence of non-union, non-weight-bearing in a plaster cast was resumed until union was demonstrated. The rods were left in place to reinforce the grafts, with one exception (Case 7) in which a protruding rod caused pain in the buttock and the rod was removed completely three years after resection.

Results

Of the twenty patients in this series (Table I), ten were male and ten, female; their average age was twenty-five years (range, ten to fifty-two years). Nineteen of the lesions (twelve in the distal end of the femur and seven in the proximal end of the tibia) were located so that resection through the joint was possible. The other one (Case 12) was intra-articular and required extra-articular resection. Of the twenty resections, seven were done for frankly malignant tumors; four, for low-grade malignant tumors; and nine, for potentially malignant lesions (Table I).

In the early part of this study, a single fibular graft was used in three patients and dual fibular grafts, in one. The described technique was used in the other sixteen, although the fluted rod was used only in four of the last five patients in the series.

Tumor Control

Only one of the twenty patients (Case 2) had a local recurrence of primary osteosarcoma, and this was not discovered until he died of pulmonary metastases six months after resection-arthrodesis. The recurrence was in the soft tissues about the fibular graft.

Four of the seven patients treated for high-grade malignancy (three with osteogenic sarcoma and one with synovial-cell sarcoma) died of pulmonary metastasis at intervals ranging from six to twenty-two months after operation. The other three (Case 3, 6, and 8, all with osteogenic sarcoma) remained free of disease four to fourteen years after resection. Two of these patients (Cases 6 and 8) had received adjunctive immunotherapy [24].

Of the thirteen patients treated for low-grade or potentially malignant lesions (ten giant-cell tumors, two chondroblastomas, and one chondrosarcoma), twelve had no evidence of metastases and one (Case 13) with a giant-cell tumor had bilateral pulmonary metastasis eight months after resection of the lesion. Eighteen months after bilateral pulmonary resection and chemotherapy, however, she was without evidence of disease.

Union

In four patients (Cases 1, 9, 10, and 17), one of the four graft-host junctions failed to unite, but all sites of non-union subsequently healed four to eleven months after supplementary iliac-bone grafting (Table I).

In Case 1, the non-union occurred at the junction of the single fibular graft with the femur. It was grafted seven months postoperatively and united four months later. This boy used crutches due to his slender graft until his death from pulmonary metastases seventeen months after resection. In Case 9, union failed to occur between the distal end of the anterior femoral graft and the tibia. Iliac grafts were applied at six months and five months later union was evident. This woman was kept on crutches for a total of fifteen months after resection. She discarded her brace eighteen months after the initial procedure. In Case 10, the proximal end of the anterior tibial graft failed to unite to the femur and this area was grafted at six months. Union was solid eleven months later and this young man discarded his crutches seventeen months and his brace, twenty-one months after resection. In Case 17, the proximal end of the anterior tibial graft had not united to the femur by six months but was solid five months later, after grafting. At this time the patient discarded his crutches, and fifteen months after resection he discontinued use of the brace. The supplementary grafting procedure required an average of six days of hospitalization and prolonged the usual sixmonth period of crutch-walking after resection by six to twelve months.

The sixteen surviving patients all became ambulatory without external support (crutches or canes): thirteen within one year, one at fifteen months, one at eighteen months, and one at twenty-one months (Table I). One who was grossly obese continued to wear a long brace while attending college. Fifteen had resumed their former occupations and one, a former ballerina, had become a dance instructor. One woman sailed a two-person yacht around the world with her husband. The activities of these patients included quail-hunting eight hours a day and various occupations such as mason and beautician. All students had resumed formal education in their former schools.

Eleven of the fifteen fully rehabilitated patients could be asked whether they would undergo another procedure to achieve functional knee motion, if it were available. Three of the eleven said that they would, while eight preferred their present status.

Graft Repair

Twelve specimens were studied using fluorescent microscopy and microradiography to determine how much repair had occurred in six months. In previous studies in dogs, we found that the amount of repair is directly related to the strength of the graft, and that the graft is weakest at three months and thereafter slowly gains strength until it reaches a steady state at one year. In these human specimens, the degree of repair histologically at six months paralleled that in the dog at three months. The rehabilitation program described was based on these observations and on data on segmental human grafts from other sites [7].

Complications

Four patients had spontaneous fatigue fractures of their grafts after union had occurred and they had resumed full activity. In one patient (Case 3), who had a single fibular graft, both the graft and the rod fractured (Fig. 7-A) sixteen months after resection. The limb was then immobilized for four months in a long cast, the fracture united, and the graft subsequently hypertrophied (Fig. 7-B). This patient was active and bearing full weight fourteen years after resection. In the second patient (Case 5), who had medial and lateral fibular grafts and a Hansen-Street nail, the lateral graft fractured at eight months but the nail remained intact. The limb was immobilized in a long cast and eleven months later the fracture had healed. The patient then started full weight-bearing but died of metastases twenty-two months after resection. The third patient (Case 8), who had anterior and posterior grafts as described and a Küntscher nail for a femoral lesion, had a fracture at the mid-portion of the anterior tibial graft twenty-one months after resection and grafting. The fracture healed after he had worn his brace for four months, and he resumed full activity using no support. The fourth patient (Case 11), whose femoral lesion was treated in the manner described in Case 8, had a fracture of the mid-portion of the posterior

FIG. 7-A FIG. 7-B

Figs. 7-A and 7-B: Case 3. Fatigue fracture of a single fibular graft and Street nail.

Fig. 7-A: First postoperative lateral roentgenogram, showing the single fibular graft.

Fig. 7-B: Fourteen years postoperatively, after fatigue fractures of the graft and rod and subsequent hypertrophy of the fibular graft. The patient was bearing full weight at this time.

fibular graft thirteen months after resection. However, the fracture was discovered retrospectively on routine follow-up roentgenograms when it was partially healed. No treatment was given and the fracture defect consolidated quickly.

In each instance the patient had only moderate symptoms. Three remained ambulatory without crutches while the fracture was healing and one (Case 3) was on crutches for three months.

One patient (Case 14) sustained a traumatic fracture of both grafts and a Küntscher rod when he fell from a horse while quail-hunting eighteen months after resection. After four months in a long cast his fracture had not healed, and internal fixation (compression-plating) of the anterior graft and supplementary iliac grafting were performed. Two months later he was ambulatory on crutches, non-weight-bearing.

Another complication, not seen in this group, occurred after three of the subsequent eleven similar procedures not included in this study. During the early postoperative period the three tibiae shifted distally on the rod, distracting the graft-femur junction 0.5 to 1.0 centimeters. This complication was due to over-reaming of the tibial canal and was managed with initial success by supplementary iliac grafting performed three to six months after resection.

Four patients (Cases 4, 5, 14, and 20) had a transient

TABLE

Case	Diagnosis*	Age, Sex (Yrs.)	Site†	Rod Type‡	Graft Type§	Complications	Tumor Control¶	Survival**	Secondary Procedures
1	OS	10, M	F	S	Fi	Non-union	M	D	Iliac graft
2	OS	13, F	T	S	Fi		LR-M	D	
3	OS	14, F	F	S	Fi	Fatigue fract. of graft and rod at 16 mos.	NED	L	4 mos. in cast for fract.
4	GCT (3)	48, F	T	K	Fi/F	Transient peroneal palsy	NED	L	
5	OS	16, M	F	S	Fi/Fi	Fatigue fract. of graft at 8 mos.; transient peroneal palsy	M	D	11 mos. in cast for fract.
6	OS	22, F	F	K	Fi/T	Fatigue fract. of rod only	NED	L	½ rod removed after fatigue fract. of rod at 36 mos.
7	GCT (1)	14, F	F	K	Fi/T		NED	L	Rod removed at 3 yrs.
8	OS	27, M	F	K	Fi/T	Fatigue fract. of graft at 21 mos.	NED	L	Wore brace for 4 mos. until fract. healed
9	GCT	22, F	T	K	Fi/F	Non-union	NED	L	Iliac graft
10	GCT	20, M	F	K	Fi/T	Pulmonary embolus, non-union	NED	L	Iliac graft
11	GCT (1)	26, F	F	K	Fi/T	Fatigue fract. of graft at 13 mos.	NED	L	Rod withdrawn 1cm out of ankle at 8 wks.; fract. healed without treatment
12	SY	15, M	J	K	Fi/T	Wound slough	M	D	Pulmonary resection
13	GCT	42, F	T	K	Fi/F		M	L	Pulmonary resection
14	CB (2)	16, M	T	K	Fi/F	Transient peroneal palsy	NED	L	Open reduction, internal fixation; iliac graft for traumatic fract.
15	GCT (1)	41, M	F	K	Fi/T		NED	L	
16	GCT	49, M	F	F	Fi/T		NED	L	
17	CS	48, M	F	K	Fi/T	Non-union	NED	L	Iliac graft
18	GCT	20, M	F	F	Fi/T		NED	L	
19	CB (3)	17, F	T	F	Fi/F		NED	L	Rod shortened 4cm because of buttock pain
20	GCT	52, F	T	F	F	Transient peroneal palsy	NED	L	

* OS = osteosarcoma; GCT = giant-cell tumor; CB = chondroblastoma; CS = chondrosarcoma; SY = synovioma; and numbers in parentheses denote prior recurrences.
† T = proximal end of tibial; F = distal end of femur; and J = intra-articular site.
‡ S = Hansen-Street rod; K = Küntscher rod; and F = fluted, curved rod.
§ Fi = fibular graft; F = femoral graft; and T = tibial graft.
¶ M = pulmonary metastasis; LR = local recurrence; and NED = no evidence of disease.
** L = living and D = dead.
†† LB = long brace; Cr = crutches; Ca = cane; and FWB = full weight-bearing.

peroneal-nerve palsy that recovered completely before external support was discontinued and did not delay rehabilitation. In one patient (Case 11), the rod was inadvertently driven into the ankle joint and was then withdrawn one centimeter eight weeks postoperatively without disturbing the reconstruction. Two and one-half years after operation the patient had no ankle symptoms. As already noted, one patient (Case 7) had the rod removed at three years because of mild symptoms in the buttock due to a bursa about the proximal tip of the rod. Another patient (Case 19) had mild pain in the buttocks caused by a rod that protruded six centimeters above the femur. After four centimeters of the rod had been cut off with a special saw, she was asymptomatic. One patient (Case 6) had a fatigue fracture of the rod without fracture of the grafts thirty-six months postoperatively. The proximal half of the rod was removed and she remained active with no symptoms. In another patient with a fatigue fracture of the rod (Case 3), the broken rod caused no symptoms and was not removed. In Case 10, the only patient who had to wear a hip-spica cast because the fixation was not stable after resection of a femoral giant-cell tumor, a pulmonary embolus developed but resolved uneventfully after appropriate anticoagulation.

There was one major surgical complication (Case 12) in a patient who two weeks before admission had had an arthrotomy for "internal derangement" done through a medially placed incision. The derangement was due to an intra-articular synovioma, and the patient was referred to our institution where an extra-articular resection was performed. The midline anterior incision was detoured medially to excise the previous scar, forming a laterally based flap that measured ten by eleven centimeters and covered the mid-portion of the anterior graft. The flap sloughed and was debrided at three weeks, exposing the mid-portion of the anterior graft and the underlying rod (Fig. 8-A). With antibiotics and wound care given through a window in the

I

Follow-up (*Yrs.*)	Fate of Grafts	Results/ Function††	Postop. Occupation	Comments
1.6	United	LB-Cr	Part-time student	Kept on crutches to protect slender graft until he died
0.5	United	LB-Ca	Part-time student	Died at 6 mos.; never active, but ambulatory
14	United and hypertrophied	FWB	Homemaker, maid	Raising 2 children; asymptomatic broken rod *in situ*
10	United	FWB	Homemaker	Plays golf, sailed with husband around the world
2	United	FWB	Student	Water-skied; died of metastases at 22 mos.
7	United	FWB	Beautician	Raising 2 children
6	United	FWB	Nurse	Plays raquetball
4	United	FWB	Lawyer	Fishes
3.5	United	FWB	Secretary	Delayed full activity to 18 mos.
2.5	United	FWB	Student	Fixation not stable, spica cast until union; delayed full activity to 21 mos.; plays basketball
2.5	United	FWB	Dance instructor	Sails
1	United	LB-Cr	Student	Never active, but ambulatory postop.; died of metastases
2	United	FWB	Homemaker	Gardens, dances; currently NED
2	United	FWB	Student	Hunts, subsequent traumatic fract. of grafts and rod now healing
2	United	FWB	Engineer	Hikes and camps
2	United	FWB	Brickmason	Built own home
2	United	FWB	Investigator	Returned to full activity at 15 mos.; rebuilds jet engines
1.5	United	FWB	Security guard	Water-skis
1	United	LB, FWB	Student	Brace due to obesity; full activity
1	United	FWB	Homemaker	Gardens

cast, the patient was able to remain ambulatory. At eight months the grafts were united at both ends and the exposed, necrotic central portion of the anterior graft was covered with clean granulations. A routine chest roentgenogram made prior to performing a proposed cross-leg flap procedure revealed bilateral pulmonary metastasis. Despite pulmonary resections and chemotherapy the patient died fourteen months after the first operation. Postmortem studies showed no local recurrence, union of all four graft-host junctions, and sequestration of the central portion of the anterior tibial graft (Fig. 8-B).

Discussion

Resection is a well established way to control recurrent benign, potentially malignant, and low-grade malignant lesions (chondrosarcoma, parosteal osteosarcoma, and grade-I fibrosarcoma)[3,4,10,12,13,17,20,21,25-30,32-37]. The effectiveness of resection as opposed to curettage or primary radiation therapy is also well established for giant-cell tumor, the commonest potentially malignant tumor about the knee[4,5,10,17,23,30,34,37]. During resection performed as described, priority must be given to tumor control. The amount of tissue removed cannot be influenced by functional considerations if the procedure is to provide optimum tumor control. It follows that angiography, isotope scanning, arthrography, and tomography are frequently required to determine the appropriate planes for adequate resection, especially when there is pathological fracture, intra-articular extension, or extra-osseous involvement of the soft tissues. Under these circumstances, questions as to the adequacy of resection become most difficult to answer, but in general we favor above-the-knee amputation rather than doubtfully adequate resection. However, if the criteria we set forth are clearly met, we believe that resection offers as good an opportunity to control the tumor as amputation, and base our decision as to therapy on patients' needs and wishes. In some situations, patients prefer and need amputation, and should be so treated.

Based on correlations of our extensive observations of pathology and of the clinical course of patients operated on, we believe that adequate resection of a low-grade or potentially malignant lesion requires removal of the lesion within an intact cuff of normal tissue that completely surrounds the lesion (removal *en bloc*) and that the bone containing the lesion must be divided at least four centimeters beyond the furthest evidence of microscopic involvement[6,32,33]. Furthermore, all tissue planes potentially contaminated by a previous biopsy or a pathological fracture must be removed

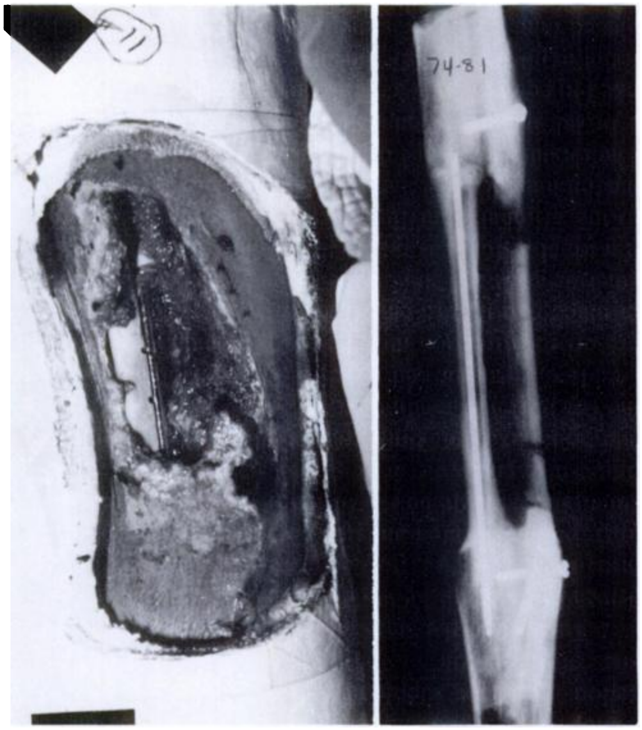

FIG. 8-A FIG. 8-B

Figs. 8-A and 8-B: Case 12. The patient had a skin slough after extra-articular resection-arthrodesis for a synovial-cell sarcoma (see text).
Fig. 8-A: Wound slough, exposing rod and anterior graft.
Fig. 8-B: Roentgenogram of postmortem specimen, showing the ends of each graft healed with the central exposed portion of the anterior graft sequestrated.

en bloc with the lesion. We examine the resected tissue by gross and microscopic techniques immediately after removal to confirm the adequacy of the procedure. If it is inadequate or if there is any doubt, further resection is done immediately, and we excise too much rather than too little normal tissue.

We favor resection over curettage or excisional biopsy in all but the most favorable circumstances, and prefer resection to cryosurgery (with which we have no experience) when the lesion involves or is in close proximity to articular cartilage, when the overlying soft tissue has been previously violated by surgery or fracture, or when the precise extent of the lesion cannot be determined.

The indications for resection as a method of treating frankly malignant lesions (osteosarcoma, high-grade chondrosarcoma, fibrosarcoma, and malignant fibrous histiocytoma) are less clearly established [20,21,25-28,39]. We have performed truly *radical* resections only for carefully selected lesions, removing *en bloc* not only the tissue of origin but also a surrounding zone of intact, normal tissue [33]. Rarely can one establish that a malignant tumor about the knee is confirmed intra-osseously. If the lesion has invaded the soft parts, particularly posteriorly, any attempt at radical resection usually involves some compromise of the principles mentioned. Anything less than a true radical resection involves unwarranted risk of recurrence and is contraindicated [33]. However, it is recognized that with the development of adjunctive measures (radiotherapy, chemotherapy, and immunotherapy), less radical surgery may become feasible. To date, we have used radical resection for only eight of the 114 sarcomas involving the distal part of the femur, knee joint, or proximal part of the tibia seen at our institution [33].

In earlier reports of reconstruction by arthrodesis of the knee, the authors stressed the problems of inadequate fixation, non-union, fatigue fracture, and recurrence [13,20,21,26,27,29,35,38,39]. Merle d'Aubigné and associates [20,21] reported a recurrence rate of 10 per cent and serious complications with significant functional impairment in seven of fifteen patients. Most investigators preferred autogenous grafts and reported difficulties with large allogeneic grafts due to non-union, resorption, and fatigue fracture [7,12,29,31,38,39]. Our technique provides autogenous grafts from the same extremity, minimizing the problems in healing and repair, and the reconstructions have stood the test of prolonged vigorous function. The majority of the complications occurred in the earlier cases. The technical details of the procedure as described are important, and a surgeon with no prior experience with the procedure should perform a mock operation on a cadaver to appreciate these details.

TABLE II*

Method of Management	No. of Patients	Local Tumor Control† (*Per cent*)	Major Complications‡ (*Per cent*)	Functional Results§ (*Per cent*)
Cryosurgery [11,18,19]	28	75	35	65
Resection-allograft [25-28,36]	120	85	40	65
Resection-arthrodesis (our method)	20	95	5	95

* The percentages were derived by combining the cases quoted for the therapy indicated.

† The percentage indicates the proportion of patients who had no evidence of local disease two years or more after operation. Positive second-look biopsy specimens were considered to indicate recurrences.

‡ The percentage indicates the proportion of patients in whom a major complication adversely affected the outcome two years after surgery. Recurrence of tumor, minor infection, transient nerve palsy, fatigue fractures that healed, and non-unions that subsequently healed were not included.

§ The percentage indicates the proportion of patients who could walk without braces, crutches, or canes, and who were able to resume their former life-style within two years.

The results by this technique and other methods are summarized in Table II. It is difficult to compare results of different treatments for this heterogenous group of complex problems. The comparative results in terms of tumor control, major complications, and function shown in Table II were compiled from the relevant literature, ignoring the differing patient populations, neoplasms, surgeons, methods of reporting, total length of follow-up, and many other variables. The comparison therefore is an approximation at best and serves only to illustrate the magnitude of differences in the major therapeutic approaches.

Cryosurgery, described by Marcove and coworkers [18,19] and refined by Hickey and Jacobs [11], is 70 to 87 per cent effective in tumor control. Its chief advantage is the preservation of knee motion. Its drawbacks are the surgeon's inability to determine accurately the margins of necrosis produced by the freezing in relation to the lesion and the present lack of information as to the eventual fate of the articular cartilage and bone killed by freezing. The long-range incidence of major complications and the amount of function regained are also unknown.

The other principal method of reconstruction, resection and allografting of a half-joint [25-28,36], is 85 per cent effective in tumor control. The principal advantage of this technique is the preservation of knee motion. The principal drawbacks are the uncertain functional results and the high incidence of major complications. The combined incidence of good and excellent results after allografting in the 186 cases reported [25-28,36] was 69 per cent and the incidence of major complications ranged from 36 to 42 per cent. The results of these human allografts resemble the unpredictable outcomes of joint allografts in animals [1,2,9,14]. It will be surprising if disability in younger, active patients does not increase with the passage of time.

There are no published reports on the results of resection followed by arthroplasty with a customized total knee replacement.

The problems inherent in the reconstruction of a stable knee by this procedure after adequate tumor surgery, considering the varying amounts of muscle and stock resected, seem to be formidable indeed.

On the basis of the evidence to date, we believe that the indications for resection-fusion are:

1. A recurrent benign or potentially malignant lesion and the occasional frankly malignant lesion that involves the distal end of the femur, the knee joint, or the proximal end of the tibia.

2. A tumor located so that there is an adequate plane of uninvolved tissue between the lesion and the posterior neurovascular structures for surgical resection, considering the degree of aggressiveness of the tumor.

3. A vigorous patient whose expectations and life-style require a stable, painless extremity capable of withstanding demanding function.

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Vascular Injuries Associated with Dislocation of the Knee*

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ABSTRACT: **Two hundred and forty-five knee dislocations were analyzed including forty-one new cases. The high incidence of injuries to the popliteal artery that accompanies this lesion (32 per cent) was confirmed, and it was re-emphasized that vascular repair must be completed within six or at the most eight hours from the time of injury to avoid amputation. Of the patients not treated within that time period, 86 per cent had an amputation and two-thirds of the remaining 14 per cent had ischemic changes.**

Complete dislocation of the knee, though uncommon, can be a very serious injury because of ischemia that necessitates amputation. This complication is largely preventable if treatment is prompt and adequate. The purpose of this paper is to emphasize the frequency and the nature of vascular lesions and to define the essentials of treatment.

Materials and Methods

That this injury is infrequent was noted previously[11,14,27]. We are reporting on forty-one new, well documented cases of dislocation of the knee in forty patients: twenty-five collected over a thirty-year period at Duke University Medical Center and sixteen contributed by the members of the Piedmont Orthopaedic Society. We also reviewed 204 dislocated knees reported in the English language literature[1-4,6-11,14-19,21-30] and analyzed the two groups.

Anatomical features: A complete dislocation of the knee is accompanied by major disruption of the soft tissues and ligaments and frequently by neurovascular damage. The collateral circulation about the knee is poor. The popliteal artery traverses the popliteal fossa and is anchored above to the femur at the adductor hiatus and below to the tibia by the fibrous arch over the soleus muscle. Within the popliteal space the popliteal artery gives off the five genicular arteries: the medial and lateral superior and inferior genicular arteries and the middle genicular artery. Although these arteries do anastomose with the anterior tibial recurrent artery, they are small and usually do not provide adequate blood supply to maintain the viability of the leg. In addition, the massive trauma necessary to produce the dislocation probably injures the collateral vessels and any surgical reconstruction of the ligaments certainly does.

Using a stress machine, Kennedy[14] showed that anterior dislocation of the knee is produced by hyperextension. Anterior dislocation therefore is likely to stretch the popliteal artery, resulting in extensive intimal damage, while a posterior dislocation, if it causes a vascular lesion, is more likely to produce complete rupture of the artery.

Findings

The findings reported in the English language literature and in the Duke-Piedmont series were analyzed separately and then compared.

Dislocation and Vascular Impairment

The 204 complete dislocations of the knee recorded in the literature (Table I) were distributed as follows: anterior dislocation, sixty-one; posterior, forty-five; lateral, thirty-one; medial, eight; rotatory, nine; and unspecified, fifty. Sixty-one of these 204 limbs had impairment of blood flow distal to the knee. It cleared completely in five after reduction of the dislocation, but failed to do so in the other fifty-six. There were sixty-one dislocations associated with vascular damage: twenty-three were anterior; eighteen, posterior; one, lateral; two, medial; and seventeen, unspecified. Thus about 40 per cent of the anterior and 40 per cent of the posterior dislocations were associated with a vascular lesion.

The forty-one complete dislocations in the Duke-Piedmont series were similarly distributed (Table I): an-

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