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A New Technique for Reconstructions of Large Metadiaphyseal Bone Defects

A Combined Graft (Allograft Shell plus Vascularized Fibula)

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Surgical Principles

Tumors involving the metadiaphyseal region around the knee are often treated by intraarticular resection (and reconstructed by prosthesis or osteoarticular allografts) even when the subchondral bone could be saved and an intercalary reconstruction applied. This is due to problems associated with the reconstruction of the subarticular diaphyseal bone defects by conventional methods.

Intercalary allografts (as well as cortical autografts) have significant complication rates in terms of delayed union or graft fracture: these would be significantly increased in those patients in whom an adequate osteosynthesis for support is not feasible.

The use of a vascularized fibula alone is contraindicated because it cannot provide sufficient stability for the epiphysis and is too weak to allow early weight bearing.

The Ilizarov technique (bone transportation) is extremely time consuming and it may be at risk in patients under aggressive chemotherapy (pin tract infection, possible interference with callus formation). Furthermore, the thin subarticular segment requires an additional ring across the joint, causing knee stiffness.

The authors describe a new surgical technique to manage this surgical problem. The basic idea consists to bridge the bone defect using a massive allograft as a peripheral shell supporting a centrally placed microvascular fibular autograft. This technique was introduced by the first author in 1988 and preliminary results first described by Capanna et al. in 1989 and in 1991 [1, 2].

Advantages

Minimal internal fixation needed, even in presence of thin articular segment.

Possibility to harvest fibula with large cutaneous island.

No limit to length of harvested fibula.

Initial stability provided by allograft.

Late stability provided by hypertrophied fibula.

Osteogenic response guaranteed by vascularized fibula.

Low incidence of nonunion and graft fracture necessitating reoperation.

Disadvantages

Prolonged operating time, it can be decreased by two-team approach:

Team 1: Oncologist
Step 1: Tumor resection.
Step 2: Allograft preparation on separate table.

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Step 3: Assembly of allograft and vascularized fibula plus internal fixation.
Step 4: Muscle reattachment and/or muscle flap.
Team 2: Microsurgeon
Step 1: Dissection of contralateral fibula.
Step 2: Preparation of recipient vessels and harvesting of fibula.
Step 3: Associated procedures (biceps reattachment, screw fixation of remaining part of fibula). Wound closure contralateral leg.
Step 4: Microanastomosis.

Indications

Benign or low-grade malignant tumors, intra- or extracompartmental.

Intracompartmental high-grade malignancies (osteosarcoma, Ewing), having responded favourably to chemotherapy.

Possibility of resection leaving wide surgical margins.

In children:

Reconstruction of large metadiaphyseal defects of tibia and femur after osteotomy either through the metaphyseal or epiphyseal part of the physis.

Ankle arthrodesis necessary after tumor resection.

In adults:

Resection too close to the joint to permit reconstruction with conventional methods.

Contraindications

High grade extracompartmental tumors.

Tumors unresponsive to chemotherapy.

Need for postoperative radiation therapy. (Preoperative radiation therapy is not a contraindication.) The same applies to pre- and postoperative chemotherapy. In both instances expect higher postoperative complication rates.

Vascular anomalies should be identified preoperatively.

Patient Information

Potential risk of local recurrence, infection, nonunion, fracture.

Potential risk of disease transmission through allograft.

Possible donor site complications.

Pre-operative Work-up

An accurate study of the tumor extension should be done using bone scan, CT scan and MRI.

The distance of the proximal and distal margins of the tumor to the articular surface (and in children, to the growth plate) should be measured with MRI examination.

Angiogram and/or echo-Doppler studies should be performed on both legs to assess circulatory status and possible vascular abnormalities.

Surgical Instruments

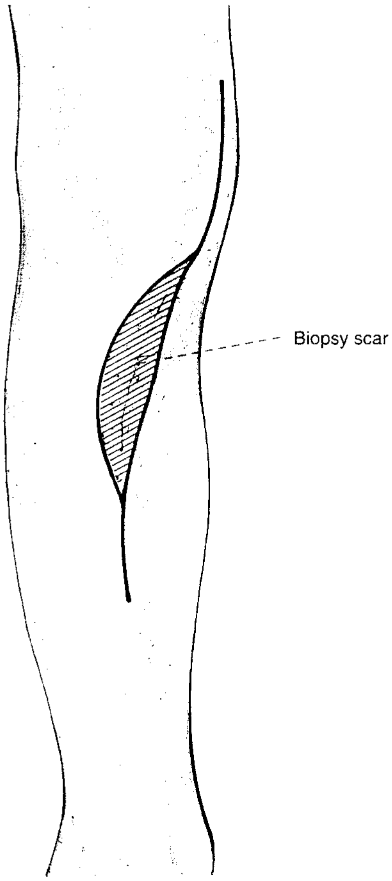
- Periosteal elevators.
- Bone clamps.
- Kirschner wires.
- Set of straight osteotomes.
- Mallet.
- Gigli saw.
- Pneumatic saw and drills.
- Luer, Liston.
- Bone curette.
- AO osteosynthesis set.
- Microsurgical instrumentation set.
- Bipolar cautery.
- Electrocautery knife.
- Operating microscope.

Positioning and Anaesthesia

- Supine position.
- Tourniquet on both thighs.
- Position of the limbs should allow for two surgical teams to work simultaneously.
- The limb on the side of resection is placed straight and is free draped to permit full flexion of the knee.
- The contralateral limb (donor site of the fibula) is positioned in such a way to keep hip and knee flexed and internally rotated whilst the foot lays upon a table.

Surgical Technique

Proximal Tibia
Fig. 1 to 26



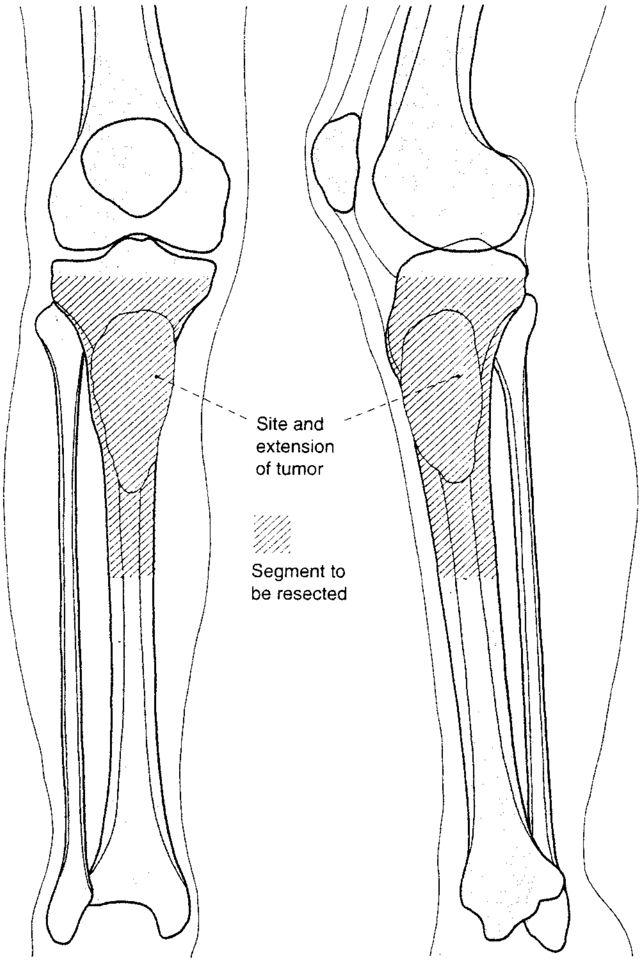


Fig. 1

Fig. 2

Fig. 1 An anteromedial (or lateral) peripatellar approach is performed with excision of the previous biopsy site. The incision is extended distally and laterally to the tibial crest. In the tibia we recommend needle biopsy to minimize the requirement for large skin removal around the biopsy site.

Fig. 2 The resection levels, planned with the help of MRI, are at least one centimeter above and two centimeters below the tumoral edges. Usually, the proximal osteotomy is above the tibial tuberosity.

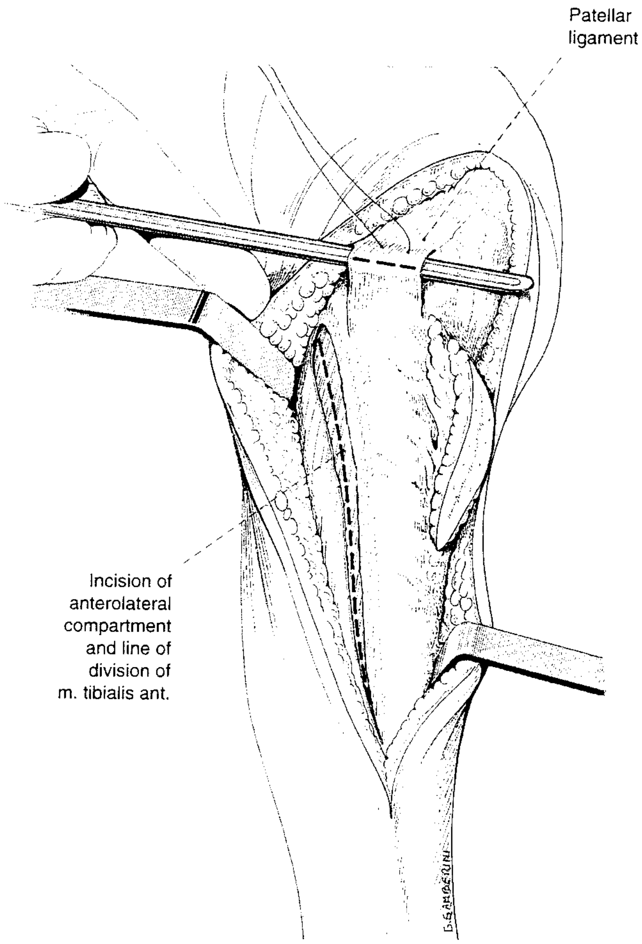


Fig. 3

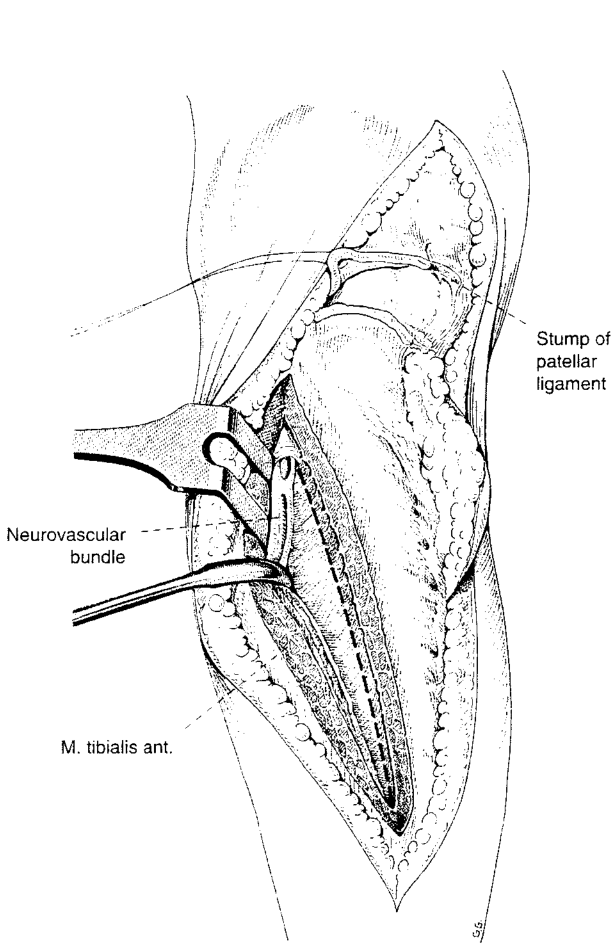
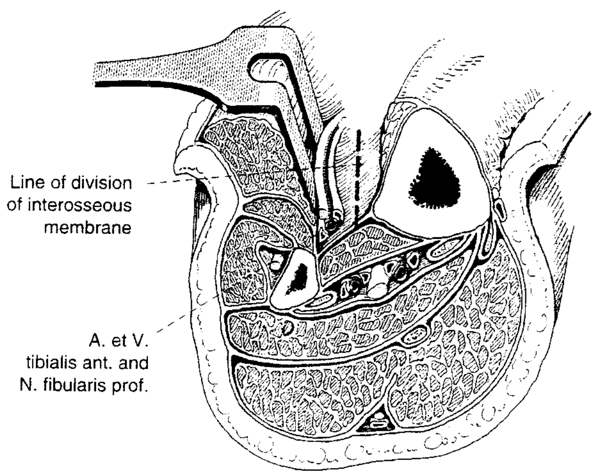


Fig. 4

Fig. 3 A subcutaneous skin flap is developed exposing the patellar tendon, the anteromedial aspect of the tibia and the anterolateral compartment. The patellar ligament is divided proximal to the tibial tuberosity. The fascia is opened along the tibial crest.

Fig. 4 The insertion of the tibialis anterior on the tibia is sectioned leaving a muscle cuff around the tumor. If required, the entire tibialis anterior muscle can be resected with the tumor. Then the interosseous membrane is exposed and the neurovascular bundle is visualized and protected.



◀ **Fig. 5** The anterior tibial vessels are prepared and retracted laterally. The interosseous membrane is divided longitudinally at distance from its tibial insertion.

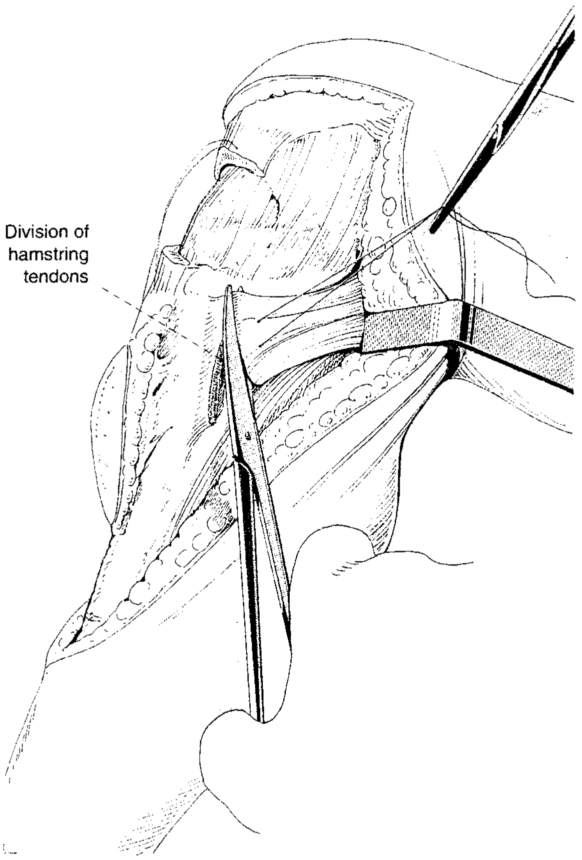


Fig. 6

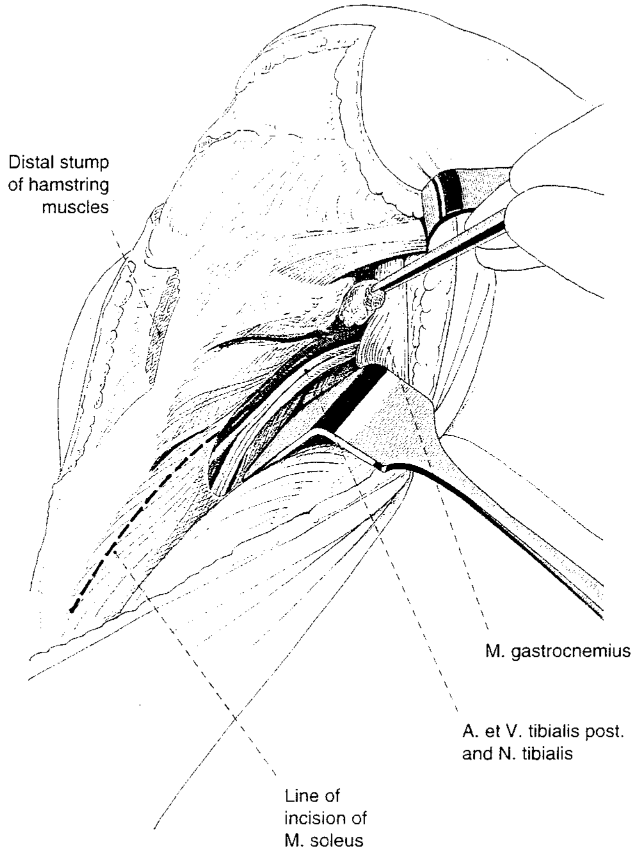


Fig. 7

Fig. 6 The subcutaneous flap is then developed medially exposing the hamstring tendons, which are divided proximally to their insertion on the tibia.

Fig. 7 The hamstrings as well as the medial gastrocnemius are reflected posteriorly, exposing the soleus (distally) and the popliteal muscle (proximally). The vessels are visualized above the popliteal hiatus.

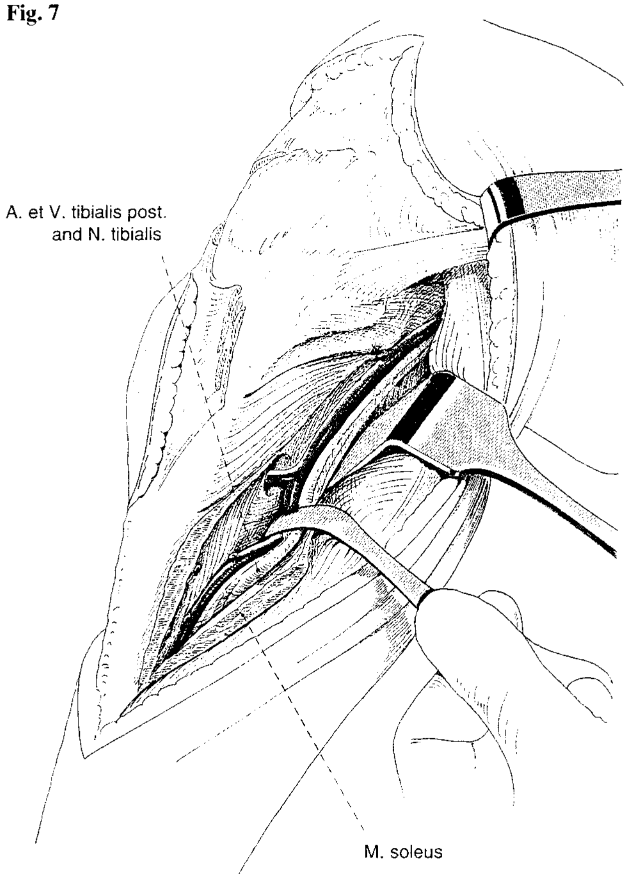
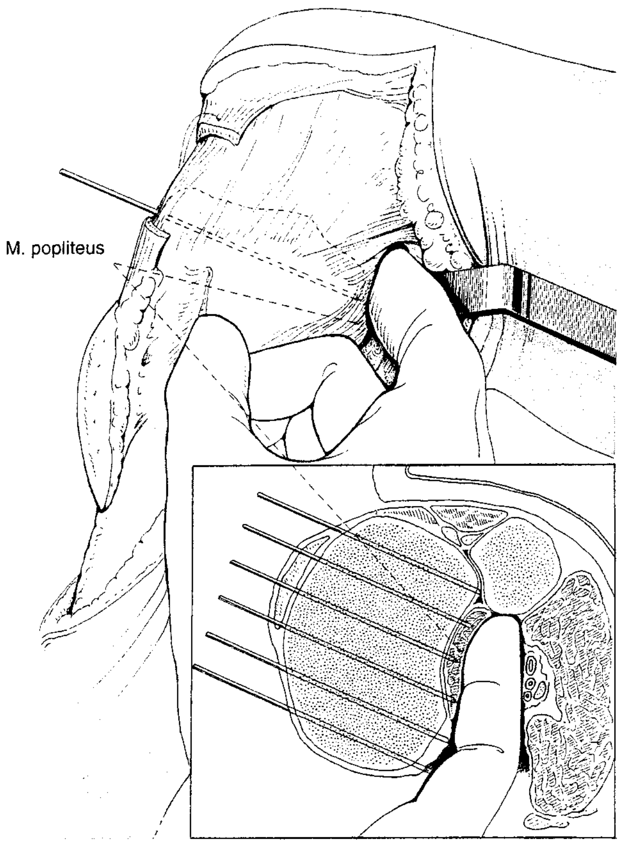
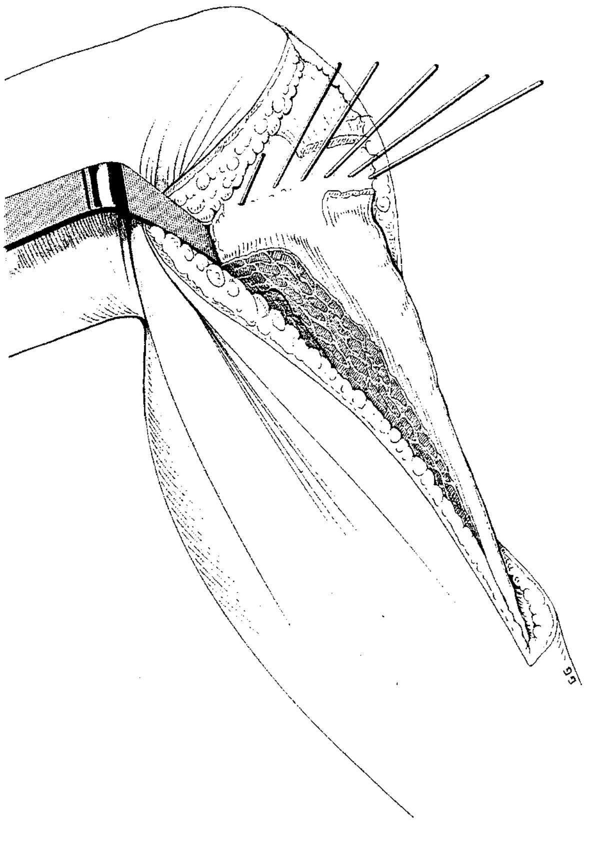


Fig. 8 Then the tibial insertion of the soleus is divided opening ▶ the popliteal hiatus and exposing the neurovascular bundle below this level.

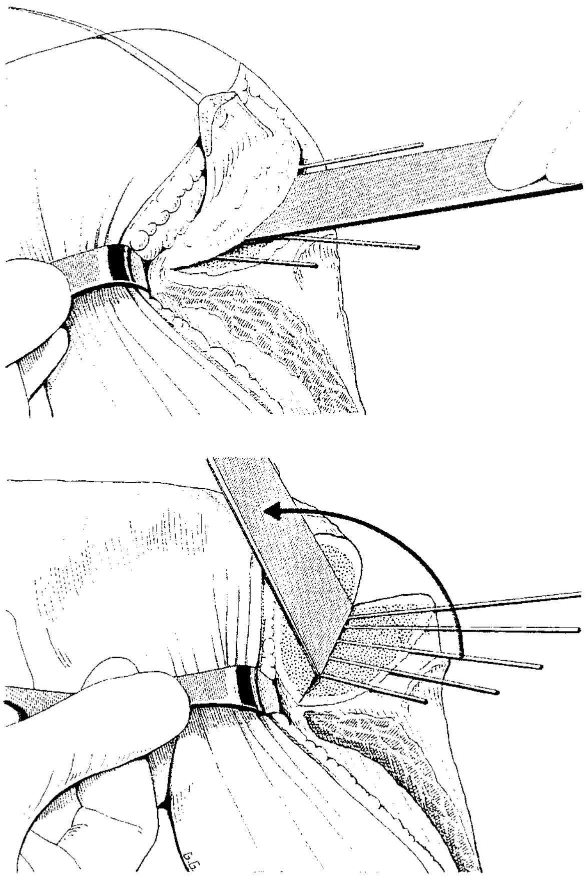
Fig. 9 The knee is flexed to 90° and a finger is introduced below ▸ the semimembranosus tendon and placed posteriorly around the tibial plateau between the popliteal muscle and the neurovascular bundle. The level of the planned osteotomy is established using as a landmark the joint surface. A Kirschner wire is introduced parallel to the joint and a radiographic control is taken to confirm that both the level and the direction are correct.

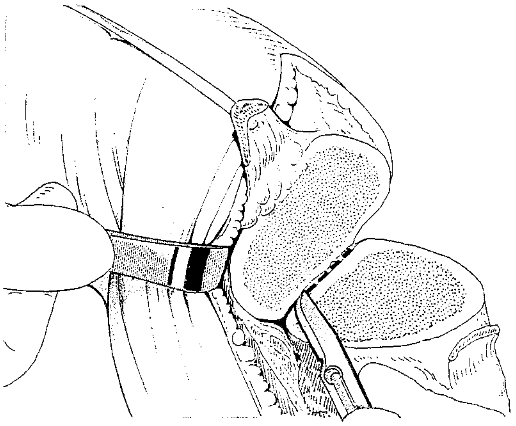




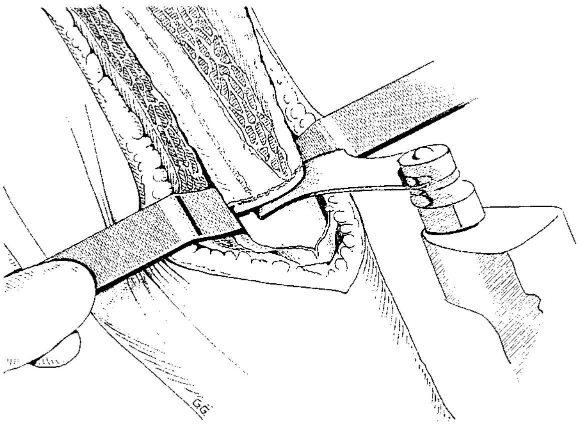
◂ **Fig. 10** Then several wires are inserted parallel to each other in the coronal plane under radiographic guidance to define the line of the juxtaarticular osteotomy.

Fig. 11 These wires act as a track for the introduction of the ▶ osteotomes which slide over them. The wires also decrease the risk of fracture of the posterior cortex with an inferior bone spike and potential tumor contamination. When the posterior cortex is cut, the knee is fully flexed while a large osteotome is used as a lever arm to open the osteotomy.





◀ **Fig. 12a** A knife is used to cut the periosteum around the posterior edge of the tibial cortex.



◀ **Fig. 12b** The distal osteotomy site is marked and the level is checked by radiographic control. The periosteum is cut circumferencially and stripped distalwards. The osteotomy is performed with an oscillating saw, or better, with a Gigli saw. A frozen section of the distal bone marrow is performed.

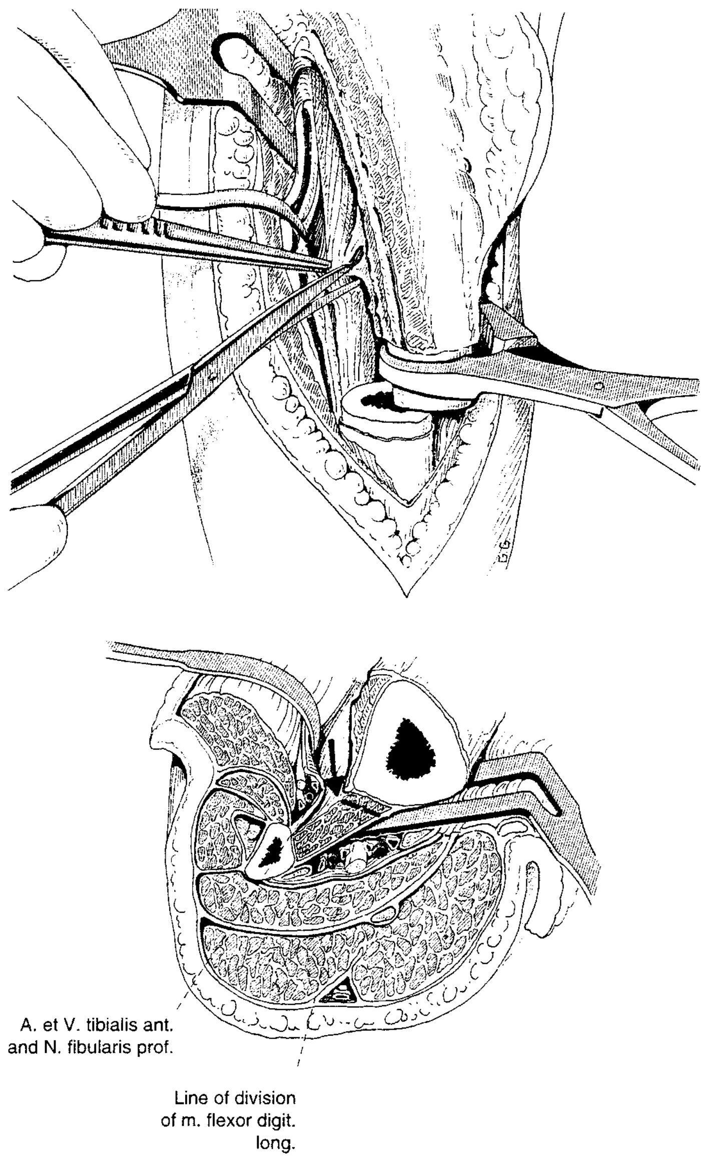


Fig. 13 The resected segment of the tibia is held with a forceps and lifted upwards. The insertion of the flexor digitorum longus on the posterior cortex and the insertion of the tibialis posterior on the posterolateral edge of the tibia are divided leaving a cuff of normal tissue around the tumor. If requested for oncological reasons, these muscles may be resected en-bloc to increase the surgical margins. Muscle detachment is performed from distally to proximally, whilst the surgical specimen is progressively lifted and rotated to facilitate the dissection. The anterior tibial vessels are protected and usually saved: if required for oncological reasons, they can be divided in the anterior compartment and in the popliteal space, and resected en-bloc with the tumor.

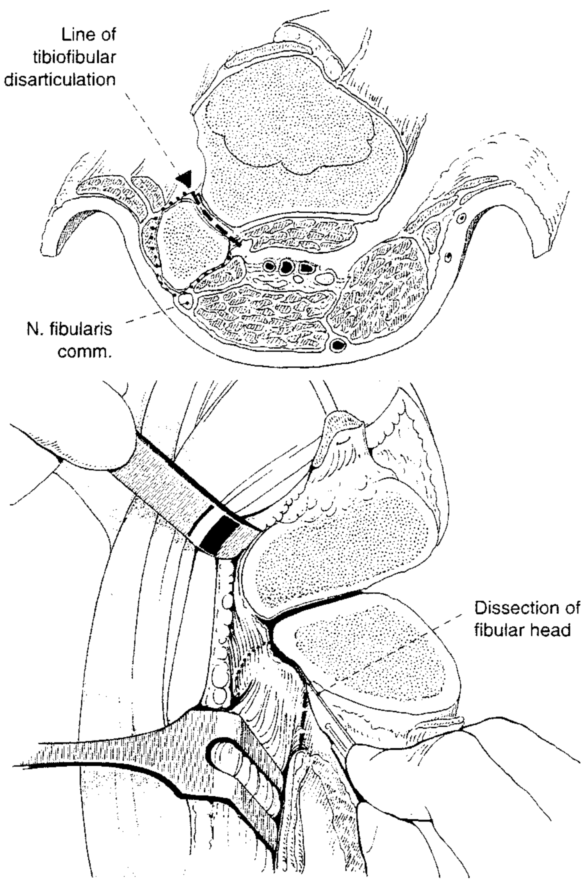


Fig. 14

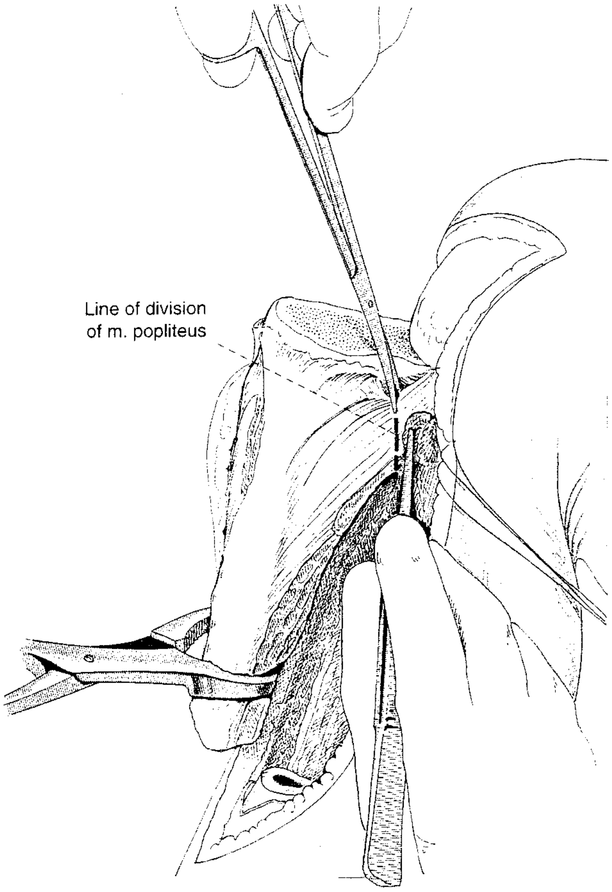


Fig. 15

Fig. 14 The tibia may be disarticulated at the proximal tibiofibular joint or, if there is any doubt of tumor invasion, the fibular head can be osteotomized at its base and resected with the tibia. In this case, the biceps and collateral ligament should be detached before and the peroneal nerve should be identified and protected.

Fig. 15 Finally, the tendon of the popliteus muscle is divided leaving this muscle as a cuff of normal tissue overlying the tumor.

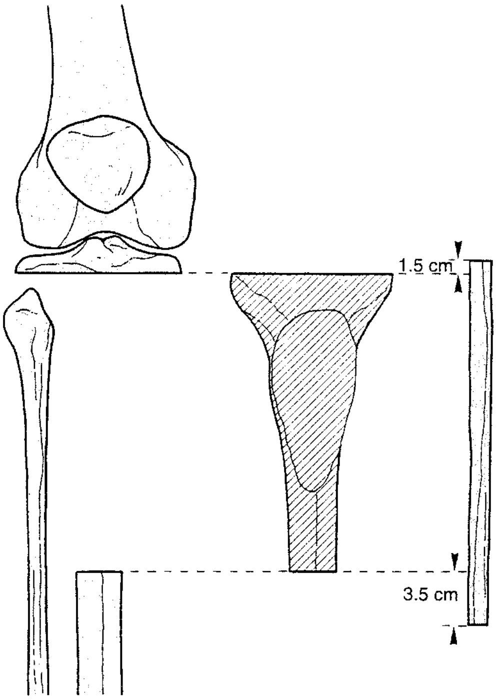


Fig. 16

Fig. 16 From the contralateral leg, a fibular segment is taken with its periosteum and peroneal vessels using the surgical technique described by Taylor [3]. The length of the vascularized fibula should exceed at least by five centimeters the length of the resected tibia. The fibular segment is osteotomized and prepared, but its pedicle vessels are not interrupted until the tumor has been resected and the allograft and the recipient vessels are fully prepared.

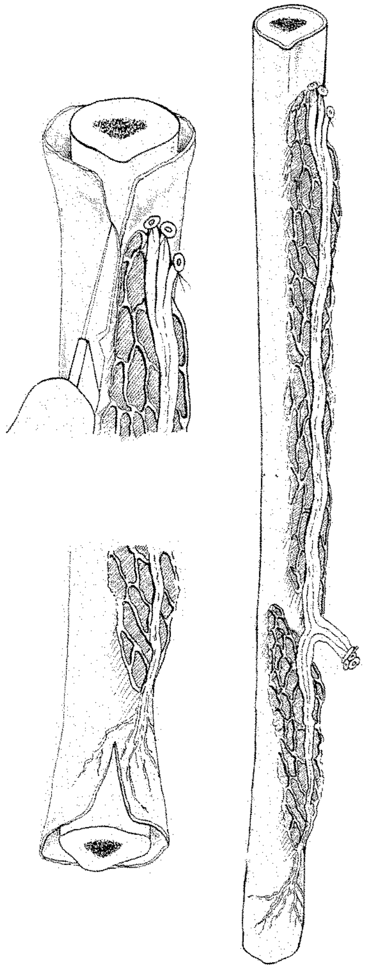


Fig. 17

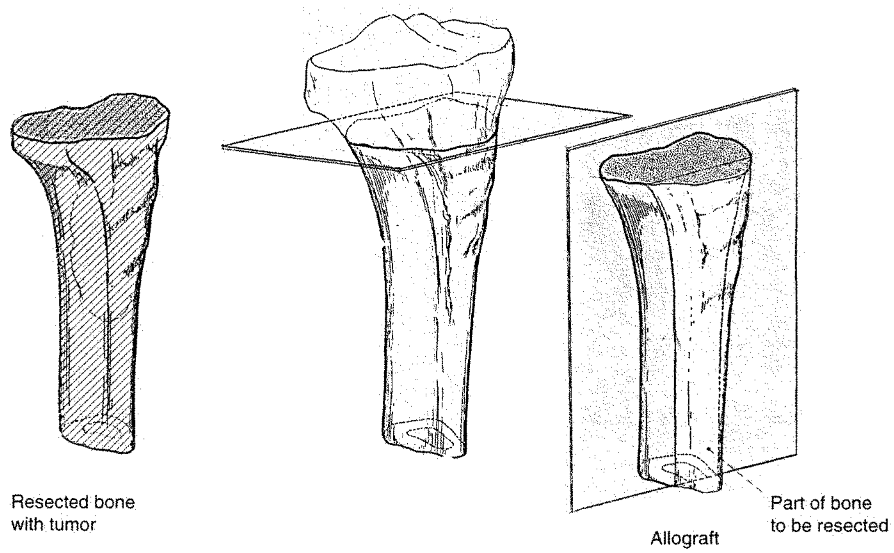
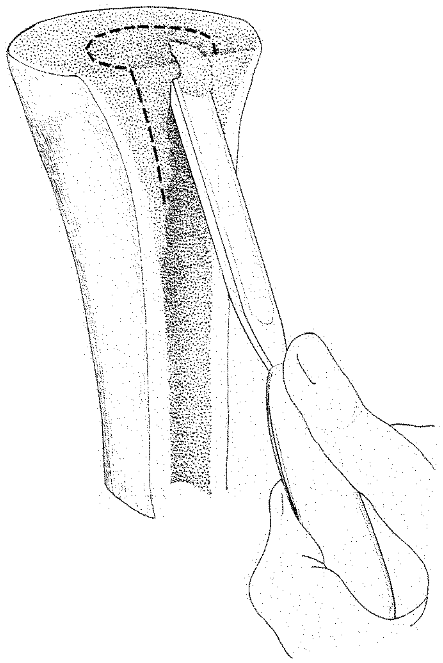


Fig. 18

Fig. 17 The fibula is then taken and its periosteum is cut and reflected at both ends.

Fig. 18 A frozen (−80 °C) tibial allograft is taken from the bone bank. It should have larger dimensions than the resected specimen. Oversizing the allograft permits the proximal osteotomy of the allograft to be made farther distally, where the cortical bone is stronger and there is no posterior protruding of the tibial plateau, but still maintaining the same area of metaphyseal bone for contact with the remaining host proximal tibia. This allows for a stronger allograft with less chance of impingement posteriorly on the neurovascular bundle. Moreover, the wider medullary canal can easily accommodate the vascularized fibula. The allograft should be 0.5 cm longer than the resection to improve stability by increasing soft tissue tension.

Fig. 19 Using an oscillating saw, the tibial crest with part of the medial and lateral cortex is removed from the allograft; the medullary canal is then cleaned. This trough is enlarged until the vascularized fibula easily fits in.



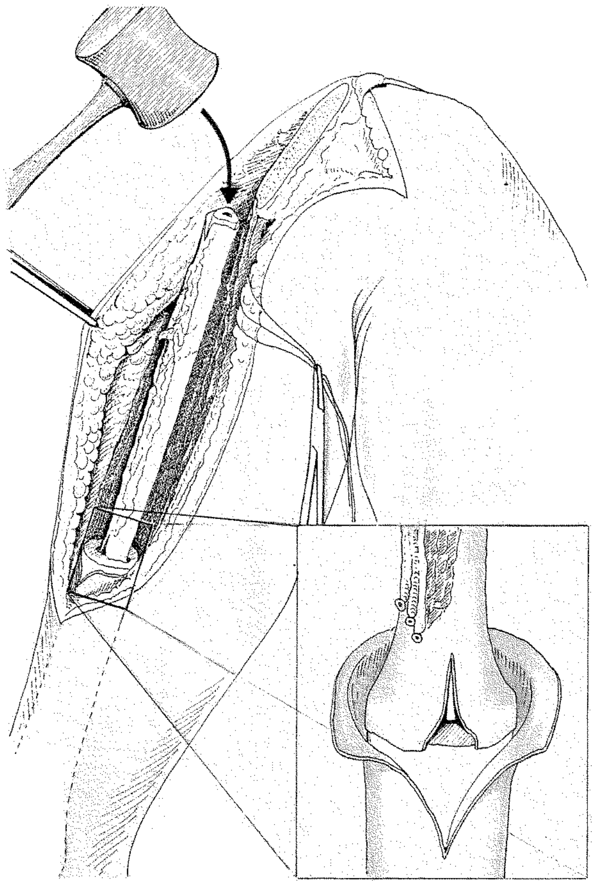


Fig. 20

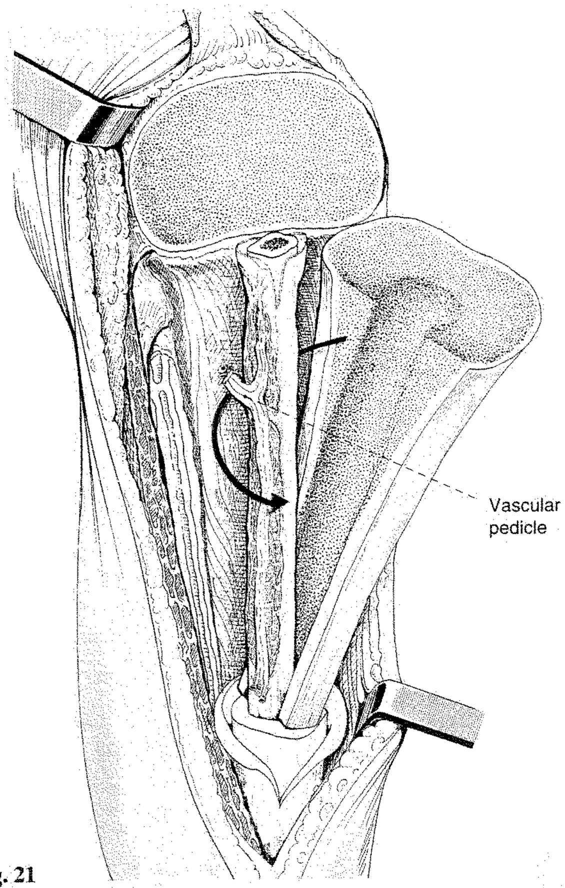


Fig. 21

Fig. 20 With the knee flexed to more than 90°, the vascularized fibula is impacted 3.5 cm into the medullary canal of the host tibia, taking care to place the vascular pedicle anteriorly. Before impacting the fibula, a decision should be made as to whether the fibula should be inserted right side up or upside down (see later). The fibular periosteum is placed around the osteotomy line.

Fig. 21 The fibula being impacted, the allograft shell is inserted by sliding it around and posterior to the fibula, simultaneously maintaining firm contact at the diaphyseal osteotomy site. In this surgical step care must be taken not to damage the vascular pedicle.

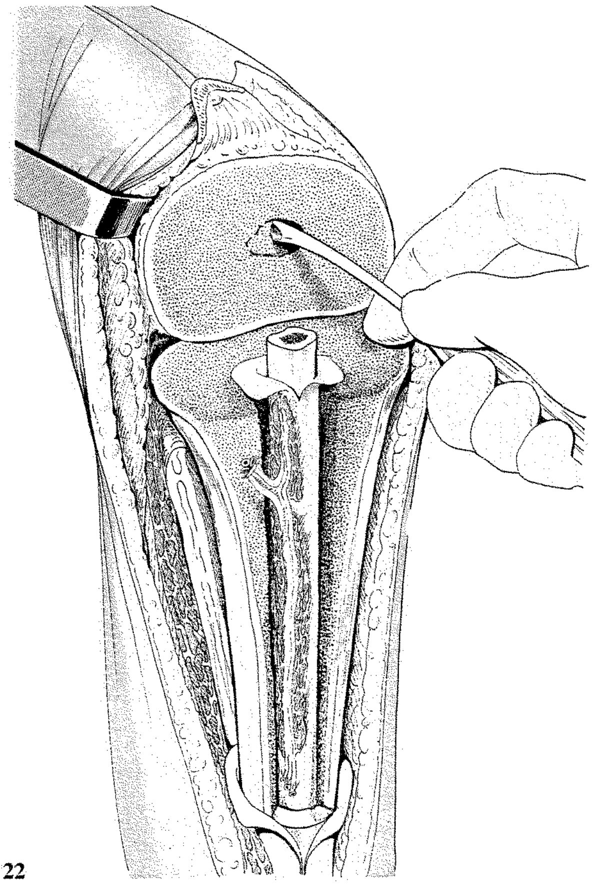


Fig. 22

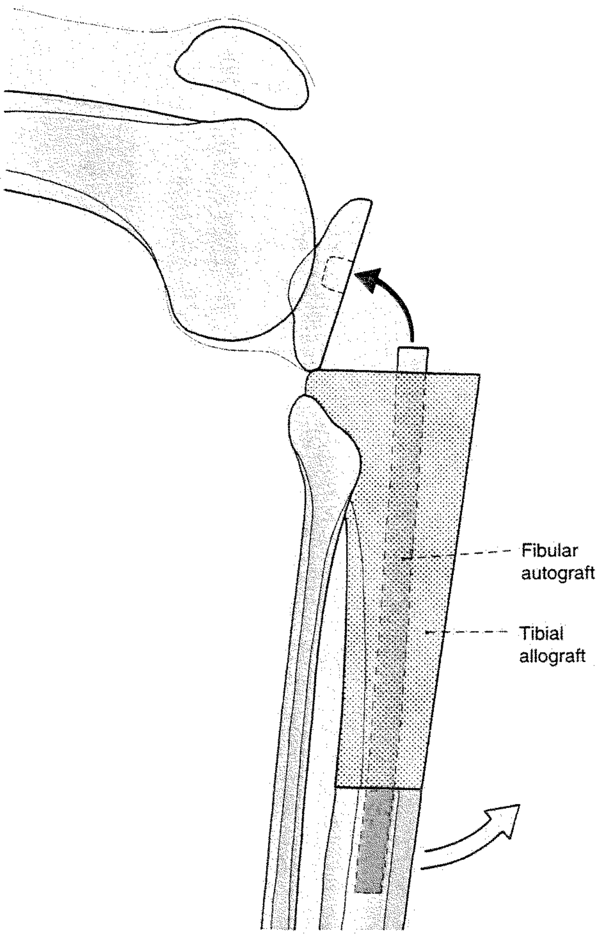


Fig. 23

Fig. 22 A slot is then made in the host tibial plateau to accept the protruding part (1 cm) of the fibular transplant.

Fig. 23 With the knee flexed at 90° the posterior cortex of the tibial plateau overlies the posterior edge of the allograft. This will provide an effective fulcrum. The knee joint is then extended, thus locking the vascularized graft into the juxtaarticular bony segment while the surface of the allograft contacts the corresponding peripheral bone.

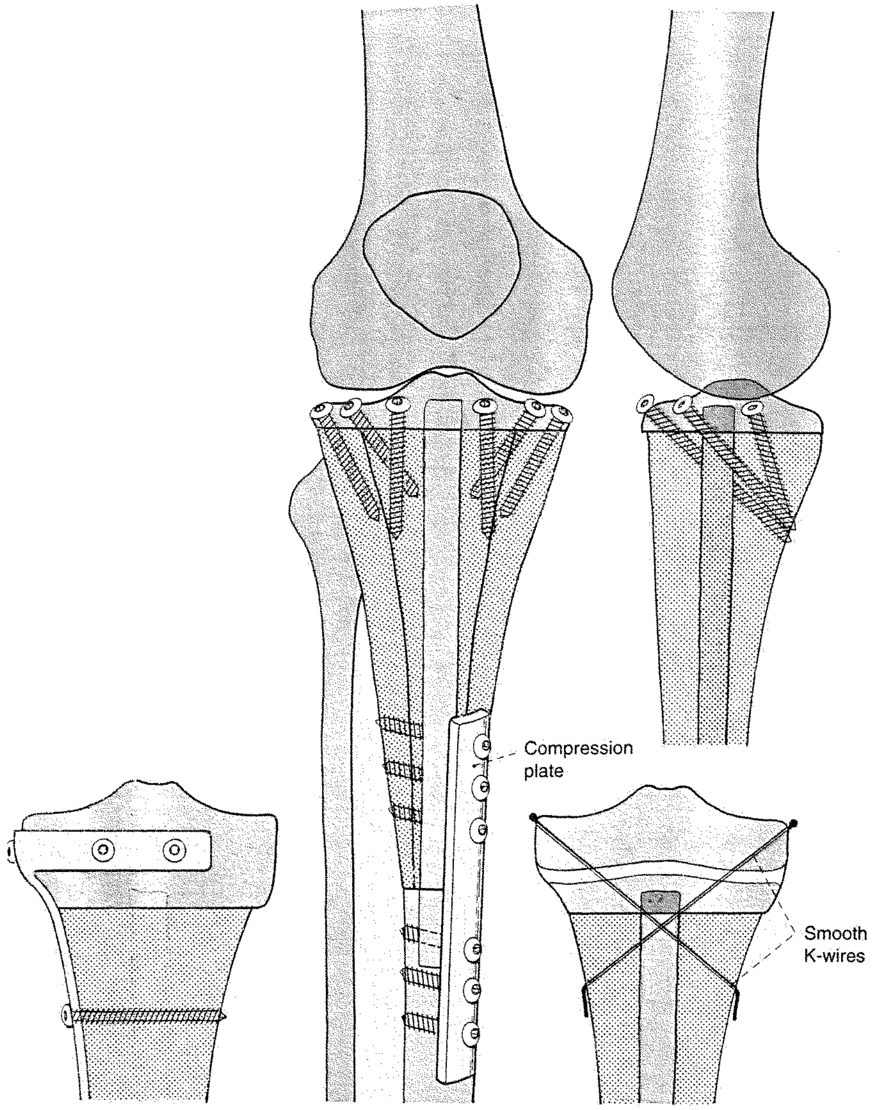


Fig. 24 In extension stability is obtained by increased soft tissue tension due to the longer allograft and by the mechanical locking of the fibula into the tibial plateau. Stability is then increased by osteosynthesis and tendon reinsertion. Minimal osteosynthesis is required and usually performed with small-fragment screws in adults or children in whom the growth plate has been sacrificed. In both children and adults a compression plate and screw fixation are employed for the diaphyseal osteotomy site, with screws also transfixing the fibular autograft. The periosteum of the tibia is reflected to cover the osteotomy line. In cases where the growth plate has been preserved, smooth Kirschner wires transfixing the epiphysis and allograft are used to avoid epiphysiodesis. Of course, if the proximal fragment is large enough, a more solid osteosynthesis using an AO plate for tibial plateau fractures is preferable.

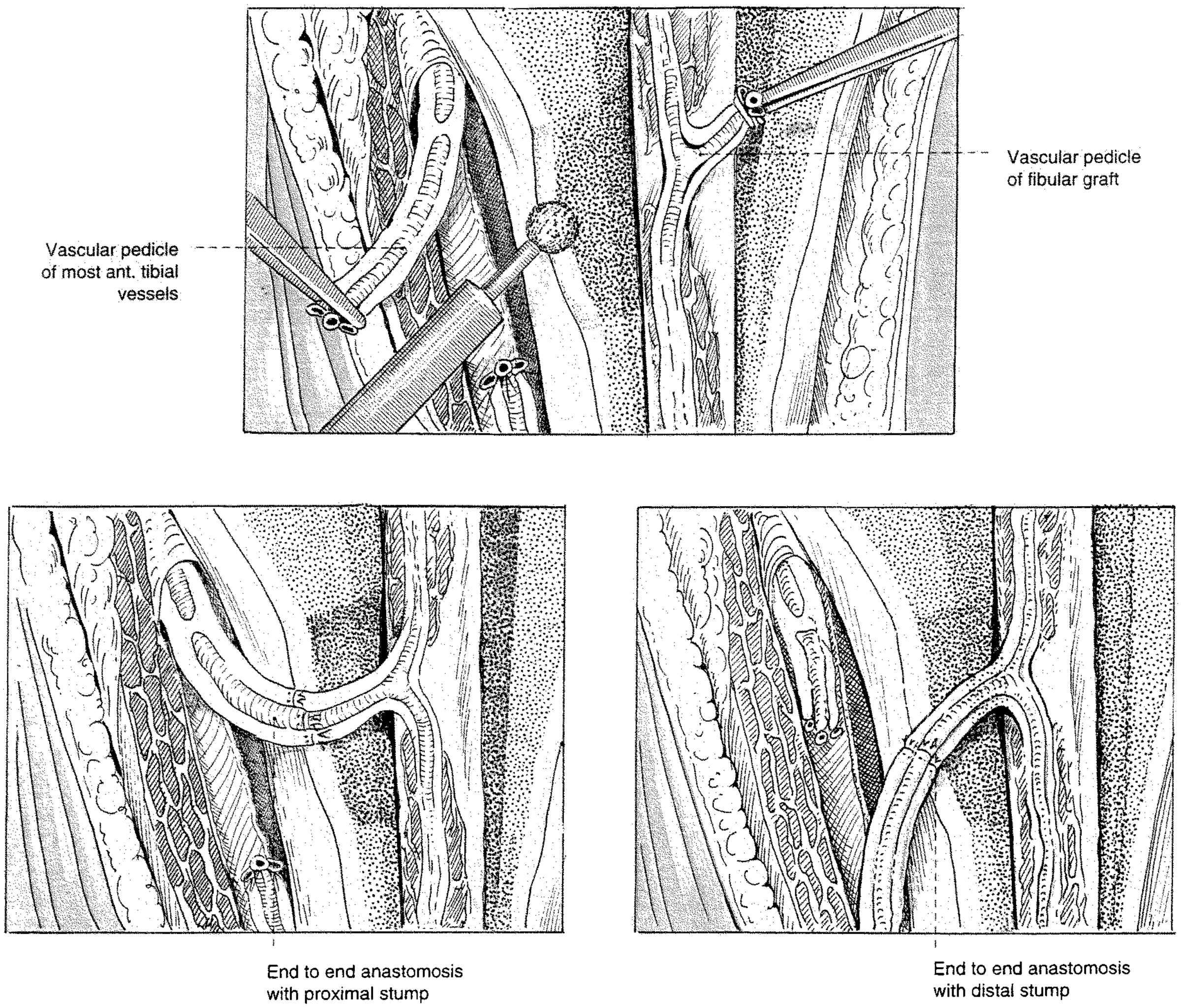
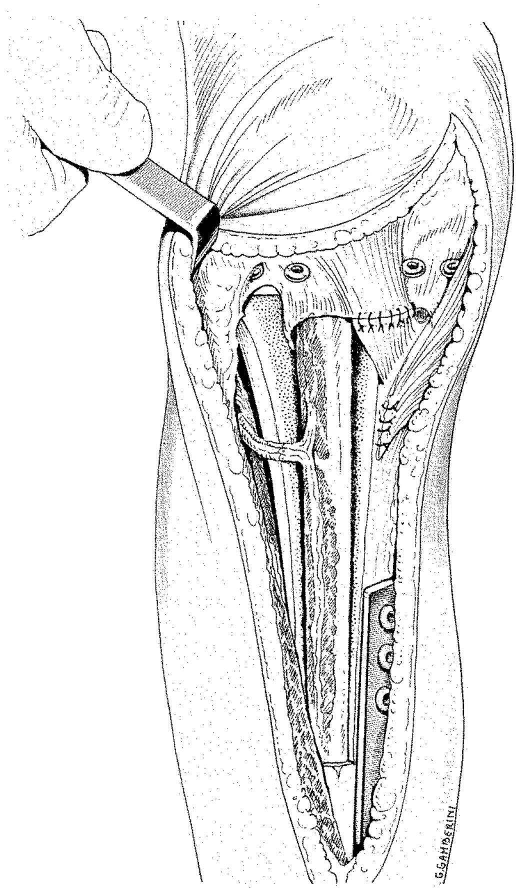


Fig. 25 Using a burr, the cortex of the allograft at the level of the vascular pedicle is fashioned into a groove, so that the vascular pedicle can pass over the allograft without kinking. The level of the anastomosis will be in the upper third (or in the center) of the implant if the fibula is inserted right side up. If convenient, the level of the anastomosis can be moved more distally rotating the fibula 180 and inserting it upside down in the medullary canal. We prefer termino-terminal anastomosis cutting the anterior tibial vessels at the desired level and obtaining a vascular loop that prevents tension on the suture. A termino-lateral anastomosis with the anterior tibial vessels may be performed if the blood supply of the foot is not optimal. Usually one arterial and two venous anastomoses are required. If the anterior tibial vessels have been resected because of oncological reasons, a termino-terminal anastomosis can be performed with the remaining distal anterior tibial artery if a sufficient backflow is present. In this case, two venous anastomoses are made with the tibialis anterior and the saphenous veins. However, if the retrograde blood flow is inadequate a termino-lateral anastomosis with the posterior tibial vessels may be considered as a better choice.



◀ **Fig. 26** Finally, the allograft's tendon insertions are used to reattach the patellar ligament, the medial hamstrings and (if detached) the biceps and collateral ligament.
Skin closure should be without tension.

Postoperative Management

Usually patients are immobilized in a long leg cast for one month. The cast is then removed and motion instituted with a continuous passive motion (CPM) machine for a few days. Following this, a second long leg cast is applied for an additional month. Patients are then fitted in a brace. Partial weight-bearing is commenced, when union of the vascularized fibula becomes evident (usually at two to three months). Weight-bearing with the brace is maintained until union of the allograft and initial hypertrophy of the vascularized fibula is evident on radiographs. Then full weight-bearing is allowed. We have found CT-scan very useful in the evaluation of morphological changes of the vascularized fibula.

Pre- and post-operative antibiotic coverage is provided intravenously for ten days, and then by oral administration for additional three months.

Within ten days from the operation, a bone scan is performed to assess the viability of the vascularized fibula.

A splint is worn for one month at the donor leg. Intensive physiotherapy is performed to avoid retraction of the flexor hallucis longus.

Special Surgical Considerations

Fig. 27

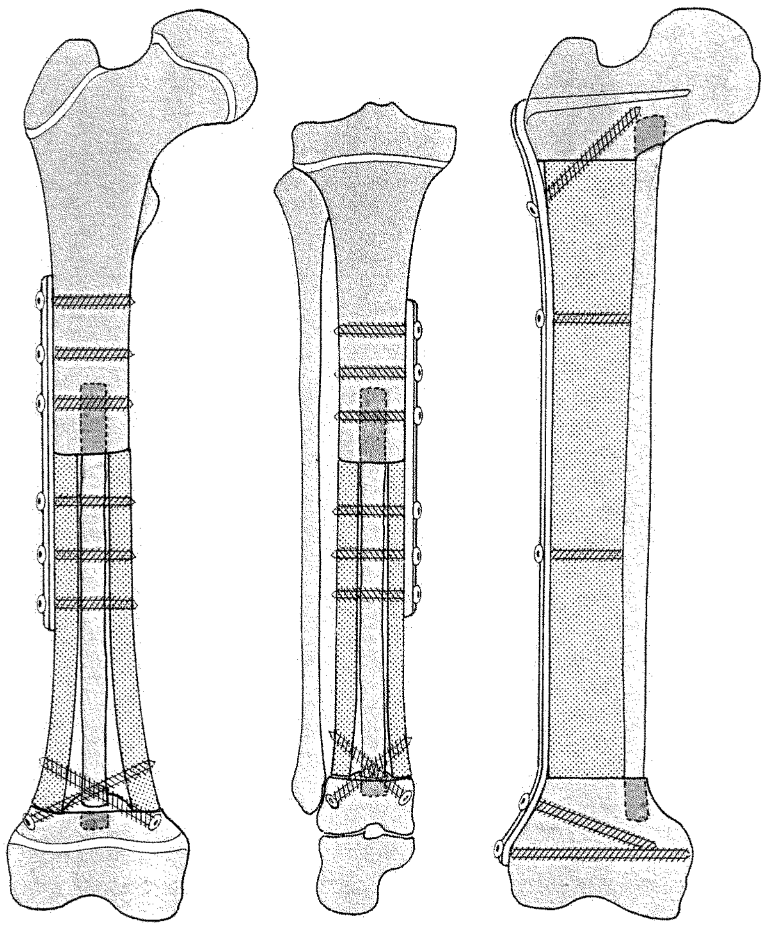


Fig. 27 In case of distal femoral metadiaphyseal resection (or in case of ankle resection arthrodesis), osteosynthesis is performed with two cortical AO screws inserted from the epiphysis (or the talus) to the allograft and crossing the osteotomy line. In case of extensive femoral diaphyseal resections we still use combined grafts, but the technique is different: a long lateral plate crossing both osteotomy lines is used, a bulky allograft is placed centrally and a vascularized fibula is placed medial to the allograft (as an additional cortical strut is a buttress), the microanastomosis being performed with a branch of the profunda femoris artery.

Intra- and Post-operative Complications

Donor site complications: Retraction of flexor hallucis longus. Ankle instability (in children or in long fibular resections). Knee varus instability (when the fibular head is also resected and reinsertion of tendons and ligaments is not performed). Injury to the lateral peroneal nerve.

Tumor site complications: Wound healing complications. Infection. Failure of the microanastomosis. Nonunion.Graft fracture or resorption. Local recurrence.

Errors and Potential Hazards

The tumor can be violated when the proximal osteotomy is performed. This error can be avoided with accurate pre-operative imaging studies, repeated intraoperative measurements and by using K-wire guidance as previously described.

The anterior tibial vessels can be injured in the tibioperoneal space. In this case, the microanastomosis is performed using the same criteria reported for patients requiring resection of the tibial vessels for oncological reasons.

Skin closure should be without tension. If a skin defect is anticipated, the fibula should be transplanted together with a large-pedicled skin island (osteocutaneous free graft) or a local medial gastrocnemius flap should be rotated to cover the anterior aspect of the tibia.

If a long fibular graft is taken including the fibular head, a careful staple reinsertion of biceps tendon and collateral ligament should be done; ankle stability should be secured fixing the distal fibula with the syndesmotic screw.

Results

Results in 14 cases operated between 1988 and 1991 were previously reported [2]. The tumor was located in the tibia in 13 patients: a resection of the proximal tibial metadiaphysis was performed in nine, a subtotal resection in two and a distal osteoarticular resection in two (ankle arthrodesis). The remaining patient had a metadiaphyseal resection of the distal femur.

A minimal osteosynthesis was employed in 13 patients (screws in eight, a short plate in five); only one patient had a long plate bridging both osteotomy sites.

There were no local recurrences. The mean follow-up was 3.5 years (from two to five years).

One patient developed a late infection (at six months) resulting in skin slough. Although bone union was achieved, the presence of chronic osteomyelitis required finally an amputation.

Union was rapidly achieved in all patients and secondary autogenous bone grafting of the osteotomy sites was never required (Figures 28a–28g).

We had no cases of displaced fractures. However, there were three cases of undisplaced stress fractures of both allograft and vascularized fibula. These did not require surgical procedures, because the vascularized fibula promoted union and showed a hypertrophic callus after cast immobilization. Partial resorption of the allograft shell was observed in two patients. In both cases it was associated with fibular hypertrophy.

Fig. 28a

Fig. 28b

Fig. 28a Low-grade fibrosarcoma of the left tibia in a 28-year old female; the MRI clearly shows involvement of the entire diaphysis and proximal metadiaphysis. A segmental tibial resection of 23 cm was required to achieve wide surgical margins.

Fig. 28b Reconstruction was performed with an allograft shell containing a centrally placed vascularized fibular autograft.

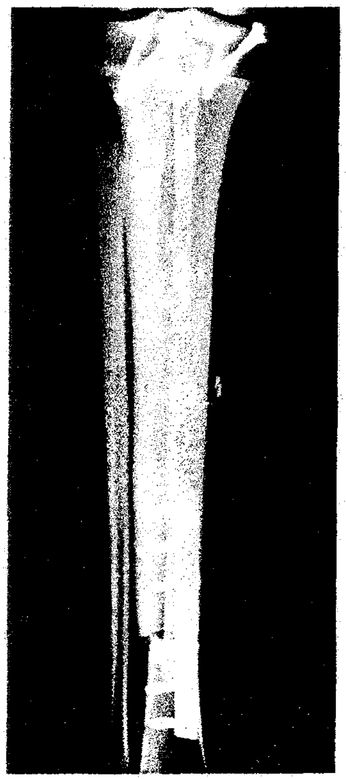


Fig. 28c

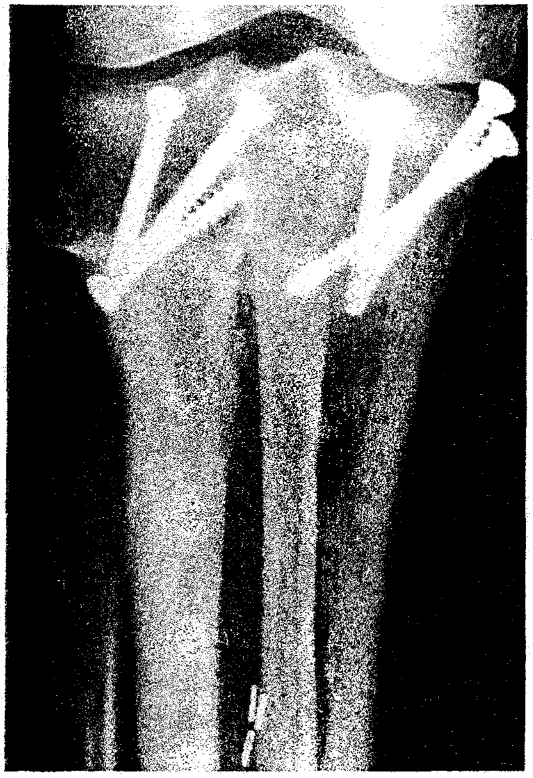


Fig. 28d

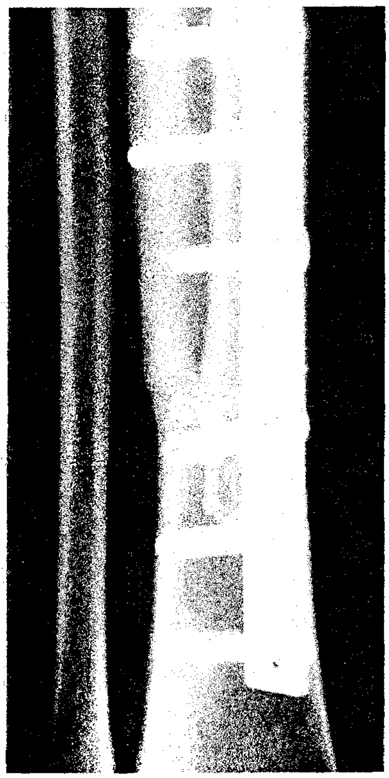


Fig. 28e

Fig. 28c Minimal osteosynthesis was used proximally (screws) while a short AO plate was used distally.

Fig. 28d and 28e Early union (within three months) was achieved both proximally and distally.

Fig. 28f

Fig. 28g

Fig. 28f and 28g The patient recovered a normal range of motion of her knee and ankle.

At follow-up, all patients are walking without external aids. All recovered a normal range of motion and stability of their knee.

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Key Words:

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