Chapter 29

# Use of Allografts and Segmental Prostheses for Reconstruction of Segmental Bone Defects

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## BACKGROUND

- An intercalary reconstruction is defined as replacement of the diaphyseal portion of a long bone after segmental skeletal resection (diaphysectomy).
- Intercalary reconstructions typically result in superior function compared to other limb-sparing procedures because the patient's own joints above and below the reconstruction are left undisturbed.
- Most intercalary reconstructions are performed with bulk allografts, although various endoprosthetic intercalary prostheses are available.
- Allograft reconstructions require osseous healing for long-term stability; initial allograft stability must be obtained with intramedullary nailing or internal fixation.
- Allografts have a long-term risk of fracture likely related to the size and type of fixation.
- Intercalary allografts are often supplemented with vascularized fibular grafts.
- Endoprosthetic reconstruction has typically been limited to small, central tumors as significant lengths of bone proximal and distal to the lesion are required for successful fixation of traditional prosthetic stems.
- New implant designs have expanded the indication for intercalary prostheses by drastically reducing the length of bone needed to achieve stable fixation.
- Segmental prostheses typically provide immediate stable fixation, allowing early rehabilitation and rapid return of function.
- Vascularized fibular grafts are not required for intercalary implants.
- Although aseptic loosening has been reported after endoprosthetic reconstruction, it is rarely if ever seen with intercalary implants; the lack of bearing surfaces contributing to wear debris formation and the lack of exposure to joint fluid help to protect the implant.

## INDICATIONS

- Intercalary reconstructions are indicated for osseous joint-sparing reconstructions.
- Intercalary reconstructions are performed most commonly in the femur, tibia, humerus, and forearm.
- Intercalary reconstructions require adequate remaining bone stock to allow stable fixation; if inadequate bone remains, the procedure should be converted to a joint-replacing reconstruction.
- Intercalary allograft reconstructions require osseous healing for long-term stability, which can be compromised by chemotherapy or radiation during the healing period.
- Intercalary allografts in areas with poor vascularity, with small residual host segments, in heavy or very active patients, or with planned radiation or chemotherapy likely benefit from supplemental vascularized fibular allografts.
- Intercalary endoprosthetic reconstruction is an option if allograft reconstruction is contraindicated due to poor host factors or in patients with prior failed allograft reconstruction.
- Modular intercalary prostheses provide the flexibility to easily convert to a conventional endoprosthetic replacement either at initial surgery or for later revisions by using joint-replacing modules at either end of the implant.

## ANATOMY

- Anatomic considerations in the femur include the anterior bow, femoral anteversion, and the proximity of the superficial femoral artery to the distal femur near the adductor hiatus.
- Anatomic considerations in the tibia include the limited soft tissue coverage anteromedially and the proximity of the posterior tibial neurovascular bundle to the posteromedial tibia.
- Anatomic considerations in the humerus include the proximity of the radial nerve to the posterior midhumeral shaft.
- Anatomic considerations in the forearm include the radial bow.

## PATIENT HISTORY AND PHYSICAL FINDINGS

- Table 1 outlines methods for examining the patient with a mass or suspected tumor.
- Important aspects of the patient history include:
  - Onset of mass or pain
  - Progression of growth or pain
  - Constitutional symptoms (fevers, chills, night sweats, weight loss)
  - Personal or family history of cancer

## IMAGING AND OTHER STAGING STUDIES

- Radiographs are the primary imaging study used in forming a differential diagnosis of bone lesions.
- Radiographs are used to assess the geometry and size of the host bone and the lesion to allow appropriate sizing of the allograft reconstruction.
- Radiographs are helpful in determining the response to chemotherapy, which influences the decision making for limb salvage.
- Bone scan is used to determine if there are additional osseous sites of disease.
- Computed tomography (CT) scanning is used to determine the bone geometry and to assess bone destruction by a lytic lesion.
- Magnetic resonance imaging (MRI) is used to assess the soft tissue extension of a lesion. It is also used to assess the prox-

**Table 1 Methods for Examining the Patient with a Mass or Suspected Tumor**

| Examination | Technique | Significance |
|---|---|---|
| Palpation | Feel the borders of the mass to evaluate size and whether it is mobile from the surrounding structures. | Lack of mobility suggests adherence to surrounding structures. |
| Joint range of motion | Assess range of motion of joints adjacent to mass. | Large masses may restrict joint motion. |
| Soft tissue evaluation | Assess soft around mass or biopsy to determine resection approach and whether sufficient soft tissue remains to allow primary closure. | Alternative methods of wound closure may be required at the time of resection. |
| Vascular examination | Assess circulation of extremity. | Vascular compromise may complicate limb reconstruction. |

imity of neurologic and vascular structures, the intraosseous or marrow extent of tumor, and extension into an adjacent joint.

- Sagittal and coronal MRI images are extremely useful in planning the resection length; measurements from the adjacent joints to the planned levels of osteotomy are made to provide a reproducible method of identifying the levels intraoperatively.
- The role of positron emission tomography (PET) scanning has yet to be defined for sarcomas. It likely plays a role in the assessment of metastatic disease.

## SURGICAL MANAGEMENT

- The main surgical decisions to be made when performing an intercalary resection are the type and length of fixation and the need for supplemental vascularized fibula graft.
- Plate fixation allows for reconstruction with standard osteosynthesis techniques.
- Plate fixation allows for compression across the allograft–host junctions, which likely improves healing.
- Plate fixation results in screw holes in the allograft, which is thought to contribute to late allograft fracture.
- Intramedullary fixation of allografts requires additional incisions but likely provides stronger fixation.
- Intramedullary fixation provides long-term protection of the allograft without placing screw holes in the allograft (**FIG 1**).
- Intramedullary fixation makes it difficult to obtain compression at the allograft–host junctions, which may impede healing.
- Allograft and host cuts can be transverse or stepped (**FIG 2**).
- Transverse cuts make rotational adjustments easier and likely result in less periosteal dissection, which may improve healing.
- Stepped cuts are more technically difficult, add surgical time, and may cause more damage to the local periosteum. However, they likely increase host–allograft bone contact, which may improve healing.
- Intercalary implants require careful attention to resection length and canal preparation to ensure optimal fixation of the implant stems.
- Regardless of the method of skeletal reconstruction, careful attention to the soft tissues and use of rotational muscle flaps when indicated are necessary to reduce the risk of wound complications and subsequent infection.

### Preoperative Planning

- Preoperative planning is extraordinarily critical in these complex reconstructive procedures.
- Multiple imaging techniques should be used to fully assess the tumor, length of resection, and the remaining bone anatomy necessary to support the planned reconstruction.
- Standard instruments for tumor resection are required, including bone saws; equipment for additional procedures such as vascular bypass, vascularized graft, or specialized soft tissue reconstruction should be available.
- Some surgeons prefer to use a separate group of instruments for the resection and the reconstruction.

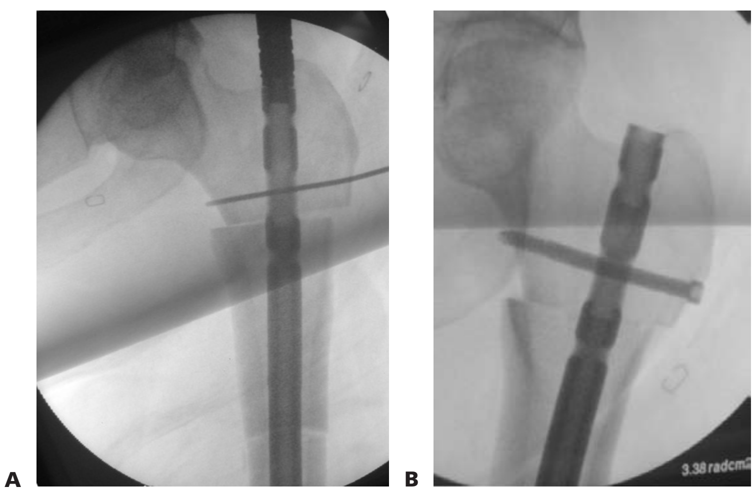



**FIG 1** • Placement of intramedullary nail and compression of junction. **A.** Fluoroscopic view of intramedullary nail through allograft in the proximal femur. The K-wire for rotational reference can be seen. Gaps in the host–graft junction are present without compression of the junction. **B.** Fluoroscopic view after placement and tightening of compression screw in intramedullary nail. Gap at host–allograft junction is minimized.

FIG 2 • Preparation of allograft. Distal allograft cut is placed in metaphysis to match host location (host location not seen). Care is taken to make smooth and perpendicular cuts in both the host and allograft bone.

- The allograft needs to be ordered from a bone bank. Some surgeons prefer to size-match allografts used for intercalary reconstructions, requiring radiographs of the allograft to be obtained before ordering.
- If a vascularized fibula graft is planned, the timing and host location of the graft must be determined.
- Endoprosthetic implants may require customized components, typically requiring a 3- to 4-week lead time to allow for design and manufacturing of the implant.
- An examination under anesthesia focusing on the rotational profile of the nonoperative leg can be useful in ensuring proper rotation of the operative leg.
- Intraoperative C-arm fluoroscopy is useful to measure and select the levels of planned bone osteotomy.

### Positioning

- Positioning depends on the tumor location and the surgical approach required for oncologic resection.
- Femoral resections are typically performed either in the supine or lateral position; tibial cases are performed supine.
- Femoral reconstructions may be facilitated by a bump under the buttock, but this may make clinical assessment of rotation more difficult.
- Forearm reconstructions are performed with the patient supine and the arm on a hand table.
- Humeral reconstructions can be performed with the patient in the supine or beach chair position.

### Approach

- The approach for intercalary reconstructions is determined by the incision needed to perform an adequate resection of the tumor.
- Femoral reconstructions are ideally performed through a lateral or anterolateral approach to the thigh; medial incisions may be necessary to isolate and protect the superficial femoral artery and vein during the resection.
- Tibial reconstructions can be performed through an anterolateral or anteromedial approach.
- An anteromedial approach is more likely to require complicated soft tissue coverage.
- Humeral resections are performed through an extensile anteromedial approach; care must be taken to identify and protect the radial nerve when oncologically possible.
- Forearm reconstructions of the radius are ideally performed through an anterior approach.

TECHNIQUES

## RESECTION

- The approach is performed as indicated by the location of the tumor and the biopsy.
- Pertinent vascular and neurologic dissection is performed to identify and protect critical structures; soft tissue dissection around the tumor mass is then performed.
- Dissection is performed down to bone at the distal and proximal extent of the planned bone resection.
- Using fluoroscopy or other measurements from preoperative imaging, K-wires placed perpendicular to the shaft of the bone may be used to mark the proximal and distal osteotomy level. Care should be taken to avoid excessive damage to the periosteum adjacent to the planned osteotomy.
- Before osteotomy, the bone should be carefully examined and marked to ensure proper rotational orientation during the reconstruction. The linea aspera of the femur is a convenient anatomic landmark; K-wires or cuts in the bone may be placed proximal and distal to the resection area as well.
- Transverse osteotomy is performed with a power saw. Cooling the saw blade with irrigant prevents excessive heat from causing thermal damage to the host bone.
- The specimen is removed, the length is measured and recorded, and margins are assessed.

## PREPARATION OF THE ALLOGRAFT

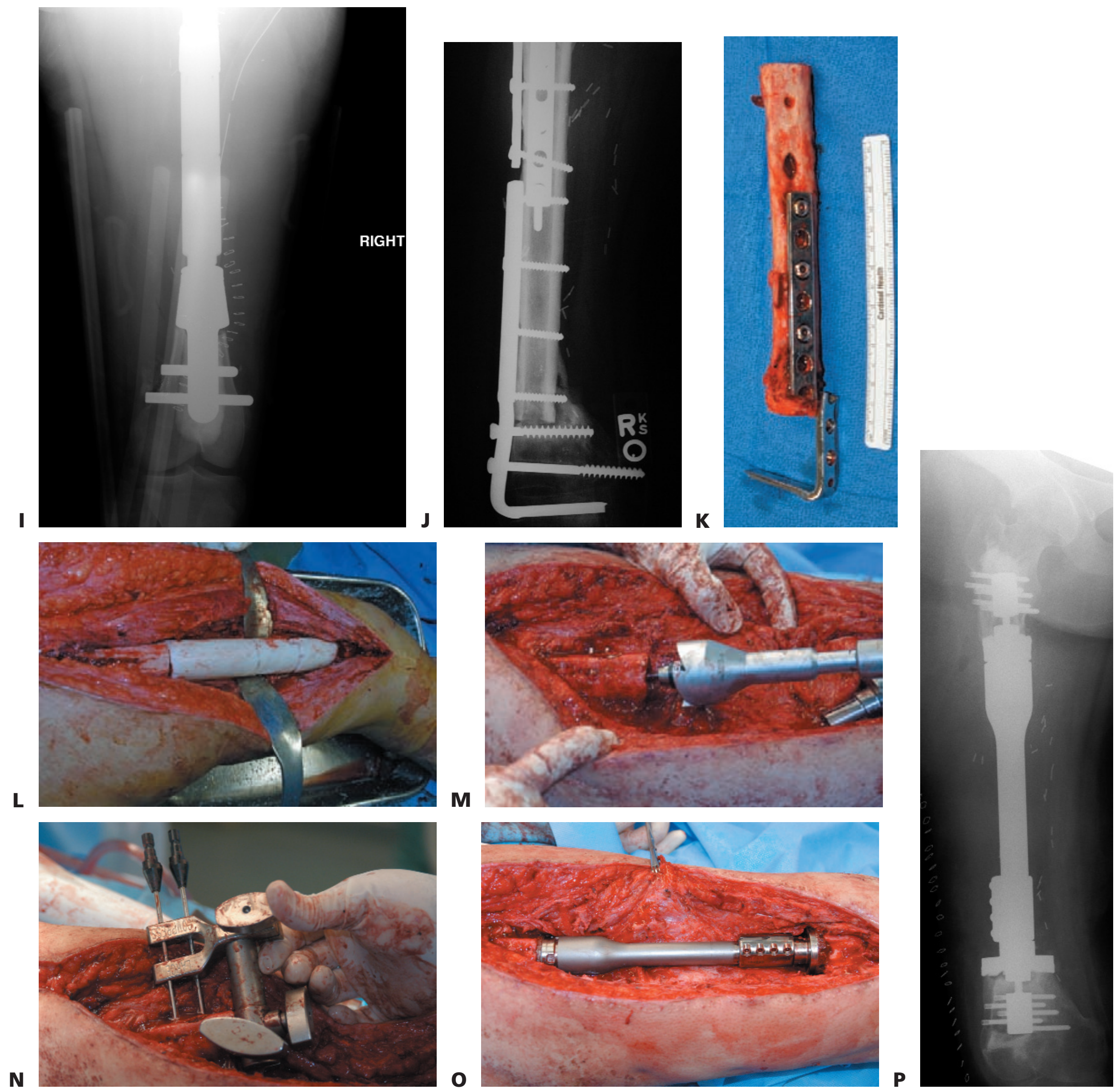
- The allograft is thawed in antibiotic-laden lactated Ringer solution.
- The section of the allograft that most closely matches the shape and size of the resected bone is marked. A few millimeters are added to the resected length to allow additional small cuts to be made to improve the bone contact and alignment with the host bone.
- The proximal and distal allograft cuts are made with a power saw.
- If intramedullary nail fixation is planned, the allograft is then reamed to a diameter 2 mm greater than the planned nail diameter.
- Reaming should be done slowly and progressively to avoid cracking the very brittle allograft.

## INTRAMEDULLARY FIXATION (FEMUR)

### Following Resection

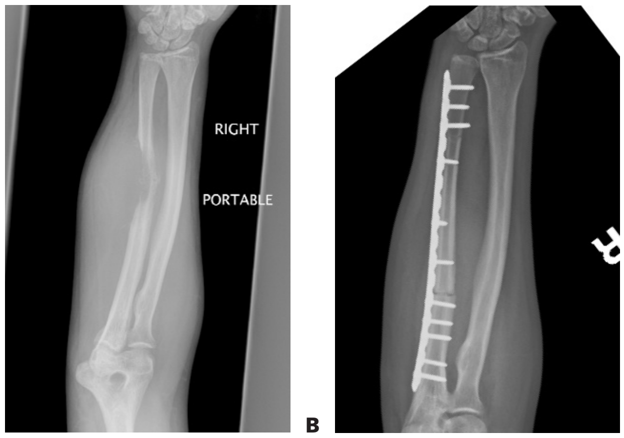
- A small incision is made approximately 8 cm proximal and slightly posterior to the greater trochanter (**TECH FIG 1**).
- A guidewire is placed at the appropriate starting point for the type of nail being used, either the piriformis fossa or the tip of the greater trochanter.
- Alternatively, if a retrograde nail is planned, a small medial arthrotomy is performed and the guidewire is inserted into the distal femur in the intercondylar notch.
- After confirming the wire position with fluoroscopy, an entry reamer is used to open a portal into the proximal (or distal) femur.


**TECH FIG 1** • **A–D.** Osteosarcoma of the femur in a 14-year-old boy reconstructed with an intercalary allograft with plate fixation. **A.** Preoperative AP radiograph showing diaphyseal lesion. **B.** Coronal MRI image showing intramedullary and extramedullary extent of the lesion. **C.** Postoperative AP radiograph showing intercalary reconstruction with medial and lateral locking plates. The most distal medial screw in the epiphysis was later removed to allow continued growth across the distal femoral physis. **D.** Postoperative lateral radiograph showing the reconstruction with callus formation at the host–allograft junctions. **E–G.** Customized modular femoral intercalary reconstruction in a patient with Ewing sarcoma. **E.** Sagittal MRI scan showing length of tumor to be resected. **F.** Resection specimen and implant; cross-pin fixation is used for improved stability of the short stems. **G.** Intraoperative view of intercalary implant; surfaces are porous for extraskeletal fixation at the prosthetic bone junctions. **H,I.** Radiographs of proximal and distal femur showing intercalary implant. *(continued)*




**TECH FIG 1** • *(continued)* **J–P.** Salvage of multiply failed intercalary allograft with conversion to intercalary endoprosthesis. **J.** Chronic painful nonunion of distal allograft–host junction despite repeated surgery and vascularized fibular bone grafting. Patient had been braced for 5 years and unable to bear weight for over 2 years. **K.** Resection of allograft with failed blade plate; cultures of allograft showed infection with methicillin-sensitive *Staphylococcus aureus*. **L.** Use of high-dose antibiotic spacer for sterilization of soft tissues while preserving limb length and tissue pocket for planned reconstruction. **M.** Preparation of intramedullary canal using facing reamer and (**N**) use of jigs for anchor plug fixation with bicortical transfixion pins. **O.** Intraoperative view of assembled prosthesis; locking collar and screws are used to hold proximal and distal body segments together. **P.** Radiograph showing final reconstruction. The patient is completely pain-free and ambulatory without braces or crutches.

- A beaded guidewire is inserted into the femur, across the resection bed, and into the femoral segment on the far side of the resection bed.
- The femur is then progressively reamed to 1.5 mm larger than the planned nail diameter.
- The beaded guidewire is partially pulled out and the allograft is inserted into the resection bed.
- The guidewire is then passed back through the allograft into the far femoral segment.
- A preliminary check of the bone cuts is made by manually compressing the allograft against the host bone and inspecting bone contact and alignment. Small revision cuts may be required on the allograft.
- The nail is then inserted. With the nail in place, a final inspection of the junctions is made and revision trimming of the allograft is performed to improve bone contact.
- The nail is fully seated.
- The locking screws in the "distal" tip of the nail are placed. These may be the screws in the proximal femur if a retrograde nail is being used.
- The nail is then backtapped to close down any gaps in the host–allograft junctions.

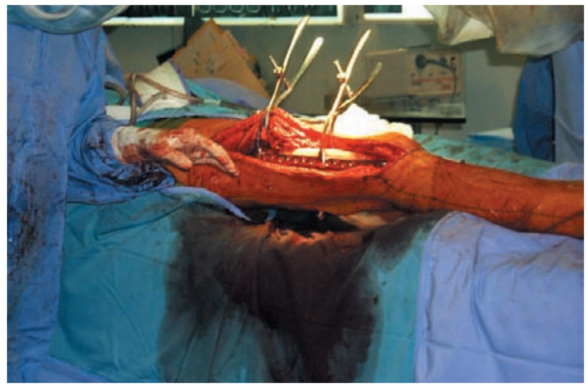



A B

**TECH FIG 2** • Grade 3 aneurysmal bone cyst with intercalary reconstruction. **A.** Preoperative AP radiograph showing lesion. **B.** Postoperative AP radiograph showing intercalary reconstruction with long plate.

- Rotation is checked either clinically or by aligning the previously placed K-wires.
- The screws in the "proximal" end of the nail are placed. If a compressible nail is being used, the compression screw is applied after placement of the dynamic locking screw (**TECH FIG 2**). Because of the extended time often required for healing, two locking screws should be placed proximally and distally.
- If compression has been applied with a compression nail and the allograft is rotationally stable, no additional fixation is required.
- If the allograft is rotationally unstable around the nail, a short plate can be applied with unicortical screws to improve stability. This can be placed at one or both host–allograft junctions depending on the amount of instability.


**TECH FIG 3** • Oblique compression screws used for fixation of a very distal host–allograft junction. Small plates can be used as an alternative.



**TECH FIG 4** • Provisional fixation of plate along femoral intercalary reconstruction. Use of clamps allows assessment of alignment and bone contact of junctions. Fluoroscopic evaluation of reconstruction should also be undertaken at this time.

## Plate and Screw Fixation

- The allograft is placed into the resection bed and gross alignment is checked (**TECH FIG 3**).
- If necessary, the plate is contoured to match the alignment of the femoral segment being reconstructed.
- A 4.5-mm plate should be used (except in the forearm). The type of plate is dictated by the location. Special plates are available for the proximal and distal femur.
- A slight prebend of the plate is performed to maximize compression of the junction on the side opposite the plate.
- The plate is positioned and fixed to one side of the host bone with one screw.
- The host–allograft segment is aligned and the plate is positioned appropriately (**TECH FIG 4**).
- Rotational alignment is checked clinically or with the previously placed K-wires.
- Compression is applied across the host–allograft segments either with a tensioning device or a Verbrugge clamp and a pull screw (**TECH FIG 5**).
- Sagittal and coronal plane alignment is verified with fluoroscopy.
- Allograft trimming is performed as necessary to improve bone contact and alignment.


**TECH FIG 5** • Compression of intercalary reconstruction with a plate. The tensioning device is seen proximally affixed to the host bone with a single screw with a distal hook into the last hole in the plate.

- Compression screws are placed into the plate to maximize compression across the host–allograft junctions.
- Two screws are placed through the plate into the allograft to prevent dislodgement. If a locking plate is being used, these can be unicortical locking screws. Alternatively, cerclage cables can be placed to avoid holes in the allograft.
- In resections resulting in very small residual host segments, large plate fixation may not be possible. In these cases, small hand or foot plates may be beneficial for fixation. Alternatively, oblique compression screws from the host through the allograft may be used.

### Closure

- Irrigation of the wound is performed and hemostasis obtained.
- If small gaps remain at the host–allograft junctions, grafting can be performed. Usually cancellous bone can be curetted from unused allograft for this purpose.
- The wound is closed in layers over suction drains.
- Efforts should be made to obtain circumferential muscle coverage over the reconstructed bone.
- A gentle compression dressing is placed. Splinting of the knee may improve patient comfort for the first few postoperative days.

## VASCULARIZED FIBULAR GRAFT

- Vascularized fibular grafts are used to supplement intercalary allografts, improving healing and adding strength and living bone to the reconstruction.
- Vascularized grafts add complexity and time to the operative reconstruction.
- Vascularized graft can be harvested from the ipsilateral or contralateral leg.
- In the femur, vascularized grafts can be placed medial or lateral, bridging across the allograft and affixed to the proximal and distal host segment.
- In the tibia, soft tissue constraints often require the vascularized graft to be placed within the allograft. A groove made in the allograft facilitates placement of the vascular graft.
- For a more complete explanation of this procedure, see Chapter ON-28.

## TIBIA, HUMERUS, AND FOREARM

- Reconstructions in the tibia, humerus, and forearm are similar.
- Intramedullary fixation may be possible in the tibia and humerus.
- Plate fixation for the humerus and tibia should be done with 4.5-mm plates.
- Plate fixation in the forearm is performed with 3.5-mm plates.
- Special locking plates designed for the proximal tibia are often useful in tibial reconstructions.
- Care must be taken in the radius to recreate the radial bow.

## INTERCALARY ENDOPROSTHETIC RECONSTRUCTION

- After tumor resection, frozen sections of the remaining medullary contents are performed to ensure margins are free of tumor.
- Careful measurement of the specimen length is necessary to ensure proper selection of components (if using a modular system).
- Preparation of the bone canal is critical to ensure adequate fixation; use of rigid instead of flexible intramedullary reamers is preferred to obtain best fit of the prosthetic stem.
- C-arm fluoroscopy is used to monitor the reaming process to avoid penetration into the adjacent joint.
- Facing reamers are used to machine the proper radius of curvature of the exposed cortical bone to ensure flush fit of the implant's stem–body junction.
- Trial reduction is performed to check length and rotation and to ensure that reduction of the prosthesis bodies is possible; the specific connection between the proximal and distal bodies varies depending on the implant manufacturer.
- For implants with cemented stems, proper canal preparation using cement restrictors, pulsatile lavage, and packing for hemostasis is performed before injection of cement and impaction of the stem.
- Uncemented systems may require further canal preparation; Compress™ implants use a number of interlocked jigs for centralization of the intramedullary anchor plug and placement of transfixion pins through the adjacent cortical bone.
- Final assembly of the prosthesis is performed per implant requirements; care must be taken to ensure that rotation is proper and that all locking mechanisms are tightened or impacted.
- Supplemental bone graft, collected during reaming, is placed at the implant–bone junction (over the porous coated surface) to provide extraskeletal fixation of the implant.
- Soft tissue reconstruction over closed suction drains is then performed. When necessary, local rotation flaps are used to ensure muscular coverage of the implant.

## PEARLS AND PITFALLS

| | |
|---|---|
| Wound healing | ■ Aggressive surgical débridement and reclosure of wounds after development of flap necrosis is critical to minimize the risk of infection. Use of flaps and skin grafts should always be considered whenever tissue appears inadequate for an easy closure without tension. |
| Limb-length discrepancy | ■ Particular attention to resection length is necessary to ensure restoration of limb length; this is less important in the upper extremity. Trial reductions are useful in ensuring proper length and rotation of the reconstruction. Marking the bone with pins before resection provides useful landmarks for the reconstruction. |
| Allograft fixation | ■ Intramedullary fixation is stronger, provides more protection against late allograft fracture, and makes restoration of sagittal and coronal plate alignment easier.<br>■ Intramedullary fixation can potentially contaminate the entire osseous segment being reconstructed if clean margins were not obtained during the resection.<br>■ Screw placement into the allograft should be minimized to decrease the risk of late fracture.<br>■ Healing time in these reconstructions can be prolonged, so every effort should be made to gain maximally stable fixation. |
| Allograft compression | ■ Compression across the host–allograft junctions should be obtained when possible.<br>■ Compression with intramedullary fixation can be obtained with various commercially available nails.<br>■ Compression with plates can be obtained with a tensioning device, clamp and pull screw, or (as a last resort) compression screws. |
| Allograft alignment | ■ Coronal and sagittal alignment can be difficult with plate fixation. This should be confirmed fluoroscopically after preliminary fixation and revision bone cuts made if necessary.<br>■ Rotational malalignment can occur with intramedullary or plate fixation. Use of alignment K-wires or clinical comparison to the contralateral limb should be performed before final fixation. |
| Host–allograft bone contact | ■ Large gaps at the host–allograft junctions can dramatically increase the healing time and union rate. Revision bone cuts or grafting should be considered if gaps remain after fixation. |
| Allograft–bone healing | ■ Healing problems are common in these reconstructions. Careful preservation of the periosteum around the resection area and avoidance of thermal injury during resection osteotomy may improve healing rates. Additional surgery to bone graft nonunions of the junctions is common. |
| Late fracture | ■ The risk of late fracture appears to be related to holes or damage to the allograft. Screws and damage to the allograft should be minimized. Use of cerclage cabling or intramedullary fixation minimizes fracture risk. |
| Intercalary implants | ■ Use of transfixion pins or bolts can greatly increase the stability of the construct, allowing greater lengths of bone to be replaced. |

## POSTOPERATIVE CARE

- Proper wound healing is critical to avoid infection of the reconstruction; use of antibiotics during the perioperative phase is extremely important, particularly with allograft reconstructions.
- Allograft patients are maintained on touch-down weight bearing until healing of the host–allograft junctions is seen radiographically (usually 3 to 12 months).
- Additional bracing is necessary only if a stable construct is not obtained. This can occur in plate reconstructions with small residual host segments after resection.
- Physical therapy should be directed toward range of motion of the hip and knee. Muscle strengthening can be performed with minimal resistance as dictated by the stability of the construct achieved in surgery.
- Intercalary implants permit immediate weight bearing; short-stemmed components around the knee are protected by placing the patient in a knee immobilizer and limiting joint range of motion to gentle assisted exercises under supervision during the initial healing stages.

## OUTCOMES

- Most studies report combined results for intercalary, osteoarticular, and allograft prosthesis composites.
- Nonunion rates are reported to be 10% to 15%.
- Late fracture rates are reported to be 7% to 20%.
- Union rates with nails and plates are nearly equal, but the late fracture rate is higher with plates.
- Functional outcomes are reported as 78% to 86% good or excellent.
- Graft survival is reported as 79% at 5 years.
- Few reports of intercalary implants have been published; individual institutional experience has been very favorable, with 100% implant survival and near to complete functional restoration of the limb.

## COMPLICATIONS

- Nonunion of the allograft–bone junction frequently occurs and may be treated with secondary bone grafting or allograft revision. Use of vascularized fibular grafts in high-risk patients should be considered to minimize this complication.

- Infection is the most common cause of allograft and prosthetic failure and can lead to secondary amputation. Aggressive surgical débridement with removal of all foreign bone or materials is necessary.
- Late fracture of massive allografts can lead to chronic pain and loss of function. Use of intramedullary fixation and avoiding screws in the allograft may help to minimize this complication.
- Prosthetic loosening rarely if ever occurs for intercalary implants. Implant failure can be revised with use of a new prosthesis.
- Degeneration of an adjacent joint after either allograft or intercalary implant reconstruction can be treated with surface-replacing total joint arthroplasty.

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