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Rotationplasty: Beauty is in the Eye of the Beholder

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Abstract

Rotationplasty is an alternative reconstructive strategy after sarcoma resection that often gets overlooked due to concerns about cosmesis. “Rotating” a distal segment 180 degrees and fixing it to a proximal segment leaves a highly-functional, durable reconstruction that functionally compares favorably to other limb-salvage techniques. Cosmetic outcomes have no discernible impact of the emotional and social functioning of cancer survivors following rotationplasty. This chapter discusses techniques of rotationplasty, as well as its oncologic, functional and emotional outcomes.

Keywords

rotationplasty; Van Nes; skeletally immature; reconstruction

Introduction

Rotationplasty is a durable and biologic reconstructive option after resection of lower-extremity sarcomas in skeletally immature patients. Rotationplasty is an alternative to amputation, allograft reconstruction, and endoprosthetic reconstruction, avoiding issues of phantom pain, limb-length discrepancy, and endoprosthetic complications (loosening, infection, and wear). Rotationplasty is also a viable option when extensive soft tissue extension of a tumor involves the vessels, as resection and anastomosis of major vessels is an option. In essence, rotationplasty is a procedure in which, after an intercalary resection, the distal limb is rotated 180° and fixed to the residual proximal limb allowing the “reverse” ankle joint to function as a knee joint. The patient can then be fitted for a modified transtibial prosthesis. The patient, therefore, retains relatively little internal hardware—only a plate and screws or a nail for fixation—providing a “biologic” solution of native bone composing the skeleton of the limb.

Rotationplasty was first introduced by Borggreve[1] in a patient with femoral deficiency in the setting of tuberculosis in 1930. In 1950, the procedure was popularized for the management of proximal femoral focal deficiency by Van Nes,[2] whose name has become synonymous

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with the procedure. It was not until 1981 that Salzer et al[3] first reported using rotationplasty as a reconstruction for bone deficits associated with oncologic resections.

Compared with endoprostheses, allografts, and amputations, rotationplasty patients have been reported to achieve superior functional outcomes in several studies.[4–6] Despite this, rotationplasty is rarely performed owing to concerns with the psychological effect of the abnormal cosmetic appearance of the limb.[7]

In this review, we aim to describe the surgical technique of rotationplasty, as well as provide data on outcomes and acceptance of rotationplasty. With this operation perhaps more than with any other, patient and family education are essential and “techniques” to achieve acceptance of the operation are of the utmost importance.

Indications and Contraindications

The primary indications for rotationplasty in orthopaedic oncology are lower-extremity bone sarcomas that require knee or hip resection by juxta-articular location or require resection of either the distal femoral or the proximal tibial physis in a child with significant growth remaining. Although experts differ in their opinions on the appropriate age range, less is known about the success of the technique in skeletally mature patients. Its success in younger populations derives in part because other limb-salvage alternatives—allografts, arthrodeses, and endoprostheses—are often fraught with complications in the growing child.[8] For further details of ways in which designers and orthopaedic implant companies are attempting to address the complications associated with other limb-salvage options, please see the article on endoprostheses in this issue. For the present discussion, let it suffice that in calculation of expected growth and measuring the resection, the operating surgeon can place the reversed ankle (the new “knee”) at the level of the expected contra lateral knee after growth completion, avoiding the need for revisions and lengthenings as the child grows.

The primary contraindication is a dysfunctional sciatic nerve (most often owing to the need to resect the nerve to obtain wide oncologic margins). Successful rotationplasty requires a sensate foot with functional ankle range of motion and adequate plantar flexion strength. Without these, the child cannot power the modified transtibial prosthesis and thus renders the operation ineffective.

Preoperative Planning

Standard oncologic resection planning should be performed with staging studies, plain films of the affected extremity, and 3-dimensional imaging of the affected limb and tumor. Assessment of the involvement of the sciatic nerve and vessels should be performed to determine the feasibility of limb salvage. As previously mentioned, involvement of the vessels does not preclude rotationplasty, as intercalary resection of the vessels and reanastomosis is possible. Involvement of the sciatic nerve is a contraindication to rotationplasty for femoral tumors.

In addition to standard imaging of the tumor, the operating surgeon should obtain full-length standing anteroposterior radiographs so that limb growth can be estimated using the method of Anderson et al[9] or Moseley.[10] As the distal femur and proximal tibia physes will be resected, only the distal tibia physis will be preserved. Thus, the resection length of the tibia should be templated so that the combined length of the residual femur and tibia (considering growth at the distal tibia physis) of the rotationplasty extremity will leave a center of rotation at the ankle that matches the length of the femur to the physeal scar on the contra lateral femur (considering growth at its distal femur physis).

Surgical Technique

Several methods of incision have been described. All aim to minimize skin complications and decrease the mismatch between the wider proximal thigh and the thinner lower leg. In most cases, previous biopsy tracts will be excised with the bulk of soft tissue, but attention must be paid to maintaining oncologic principles with regard to biopsy tracts. Our incision preference was described by Merkel et al[11] and consists of 2 circumferential incisions that are oblique to the long axis of the extremity. The rationale is to use greater obliquity of the more distal circumferential incision to generate a circumference length that matches the slightly more transverse circumference of the more proximal incision. Other techniques include 2 transverse incisions with distal triangular projections used to compensate for mismatch and fish mouth incisions.[12–14]

Although surgeons have different preferences for approaching resection, it is our preference to maximize margins in the resection. With this in mind, dissection is focused primarily on freeing the neurovascular structures intended for salvage from the segment to be resected containing the tumor. For a distal femur rotationplasty resection, this will include dissection of the femoral artery and vein and the sciatic nerve. For a proximal tibial tumor, this will include dissecting free as many as are salvageable of the tibial nerve, deep peroneal nerve, superficial peroneal nerve, saphenous nerve, sural nerve, anterior tibial artery and vein, and posterior tibial artery and nerve. Most surgeons will sacrifice the peroneal vessels near the interosseous membrane owing to tumor proximity. Many also sacrifice the anterior tibial artery because of the difficulty of dissecting its course between the proximal fibula and tibia. Contrarily, if removal of the proximal fibula makes the anterior tibial artery salvageable in a safe oncologic plane, it certainly may be saved. For tibial rotationplasties, neither the tibial nerve nor the peroneal branches drive important motor function in the final rotationplasty. Each is primarily sensory in function. Because of this, any may be sacrificed for oncologic principles if needed, as long as sufficient sensory innervation to the foot is preserved to facilitate prosthetic wear.

If the dissections to free salvageable neurovascular structures are facilitated by multiple longitudinal incisions through the to-be-resected segment, then multiple incisions are performed. Some surgeons prefer to perform the resection as they would for any other type of reconstruction, then address the rotationplasty after the tumor has been removed. Once the tumor contained within the to-be-resected segment is dissected free from the to-be-salvaged neurovascular structures, the surgeon prepares to make osteotomies at the appropriate levels (Figs. 1 and 2).

Before making the osteotomies, it is critical to mark rotation on the femur and on the tibia with Steinmann pins, notches with the osteotome, gentian violet stain, or some other lasting mark as rotation can be challenging to assess later in the case. Osteotomies are made perpendicular to the bone, at the levels based on preoperative templating for future limb-length equality. Although some have advocated step cuts for faster osteosynthesis, we have found the flexibility in rotation provided by perpendicular cuts to be valuable. When maximal length is required for limb-length equality and a long resection is oncologically necessary, a cut just distal to the proximal tibial physis (for a femur tumor) or just proximal to the distal femur physis (for a tibial tumor) may be indicated. The metaphyseal bone used for this osteosynthesis site has excellent healing potential even if there is size mismatch. Further, a diaphyseal cut on tumor-bearing bone may be “potted” into the soft metaphyseal bone of the other bone to encourage healing. Such potting requires additional attention to length considerations, of course.

With the intercalary segment removed, the distal segment is externally rotated 180° and brought proximally. Doppler ultrasound should be checked throughout the rotation portion of the case to make sure the rotation of the vessels does not occlude flow. Although there are several options for fixation—4.5-mm large fragment plate osteosynthesis, intramedually nail fixation, or external fixation—we prefer plate osteosynthesis. It is important to secure the plate to the distal, tibial segment first, as the cylindrical femur will allow more flexibility in rotation adjustments than the triangular tibia. If the vessels were resected during the case owing to tumor invasion, this is the point in the case where the vascular surgeon would anastomose the superficial femoral artery and vein to the popliteal artery and vein, respectively.

The fibula requires extra attention in either distal femur resection rotationplasties or long proximal tibia resections. For the former, proximal fibular physeal growth must be stopped. Some prefer to resect the proximal fibula to accomplish this. As proximal fibula resection requires mobilization of the common peroneal nerve, our preference is instead to place a longitudinal screw antegrade from the epiphysis, through the physis and metaphysis, into the diaphysis as an epiphysiodesis (Fig. 3A). For the latter scenario of a very short tibia and fibula segment following a long proximal tibia resection, ankle (now, functionally the knee) instability can result if the fibula is not fixed. With this in mind, we prefer to osteosynthesize both the tibia and the fibula into the recipient distal femur metaphysis (Fig. 3B).

With the specimen resected and vessels and nerves dissected, attention is turned to “debulking” the intercalary segment. Always protecting nerves and vessels, the medial and anterior muscle compartments are transected at the level of the osteotomy site. In the anterior compartment, the vastus medialis, vastus intermedius, and vastus lateralis muscles are transected at the level of the skin incision down to the rectus femoris. In the posterior compartment, the gastrocnemius is detached from the femoral condyles, taking care to preserve the vascular supply through the sural artery (off the popliteal artery) to each head.

Soft tissue repair is performed with heavy, generally non absorbable suture. Following distal femur tumor resections, no formal muscle-tendon transfers are necessary, as the ankle (now the knee) will be driven by the muscles that normally drive the ankle. Usually, the medial and lateral heads of the gastrocnemius, which were proximally freed from the femoral condyles with their sural artery vascular supply intact, are sutured to the anterior thigh fascia or the rectus femoris originating tendon with the foot in neutral position. The residual of the hamstrings can be optionally sutured to the extensor retinaculum of the proximal tibia, but not too tightly.

Following tibial resections, the tendon transfers of thigh musculature to ankle tendons are critical as these will drive the ankle becoming knee (Fig. 4). The musculotendinous transfers are as follows: the rectus femoris and vastus medialis muscles are repaired to the Achilles tendon, the semimembranosus and biceps femoris muscles are repaired to the tibialis anterior tendon, the semitendinosus muscle to the extensor hallucis longus and extensor digitorum longus tendons, the gracilis and sartorius muscles to the peroneal tendons, the vastus lateralis muscle to the posterior tibialis tendon, and the vastus intermedius muscle to the flexor digitorum tendon.

It is essential to maintain awareness of the course of the femoral vessels and to regularly check that distal pulses remain patent. Investing fascia is generally not closed to prevent compartment syndrome, and the skin is sutured loosely. Drains are placed, the wound is dressed, and a bulky soft dressing is placed. The use of external immobilization is somewhat controversial. Our usual practice is to splint the limb initially and place a circumferential cast or spica only after postoperative swelling has begun to resolve.

Complications and Outcomes

Vascular complications of rotationplasty include lower-limb ischemia from arterial or venous obstruction and reperfusion injury from prolonged intraoperative or postoperative ischemia.[15, 16] Sawamura et al[15] reported a 12% rate of amputation in the immediate postoperative period secondary to vascular compromise. Compartment syndromes have also been reported and the compartments must therefore be clinically monitored in the postoperative period.[16] Transient peroneal nerve palsy is also common, and therefore it is essential to note the integrity of the nerve in the operating theater.[13] Other complications include wound necrosis, pseudarthrosis, non-union and rotational malalignment.[15, 17]

Oncologic Outcomes

With the use of modern chemotherapeutic agents, oncologic outcomes in extremity sarcoma have improved dramatically and appear to have little to do with the type of reconstructive effort made by the surgeon. Oncologic stage, tumor necrosis, and surgical margins have direct effects on oncologic outcomes, but reconstructive methods appear to be equivalent.[13] Gottsauner-Wolf et al[17] reported local recurrence in 70 patients with malignancies around the knee treated with rotationplasty, after surveillance for a mean of 4 years.

Functional Outcomes

Rotationplasty patients function favorably when compared with amputation and alternative limb-salvage patients. In a large, multi-institutional study comparing functional outcomes among lower-extremity patients, rotationplasty patients were shown to have higher Musculoskeletal Tumor Society and Toronto Extremity Salvage functional scores than patients with alternative limb-sparing procedures or amputations.[4] Although several other studies have corroborated these findings,[5, 6] a single suggested functional results of rotationplasty were better than transfemoral amputation but inferior to limb salvage.[18] Perhaps most encouragingly, however, is a study by Hillmann et al[19] in which of 61patients, 85% who had undergone rotationplasty for a lower-extremity sarcoma were actively participating in "high-level" sports. In our experience, we have noted that patients with rotationplasty return to high-impact activities, such as skiing, running, wrestling, and lacrosse, without the inhibition and concern that accompanies our endoprosthesis patients who return to sport.

Emotional Outcomes

Psychosocial well-being after rotationplasty is a critical issue. The appearance of the limb is unusual and much speculation can be made into how this will affect development and emotional well-being, especially given that most of these surgeries are performed on young children. Rodl et al[7] evaluated 22 patients a decade after they had undergone rotationplasty and found that there was no reduction in psychosocial adaptation or life contentment as compared with their healthy peers. In other words, rotationplasty patients marry and have children at the same rate as other limb-salvage patients. Veenstra et al used the SF-36, Social Support List, European Organisation for Research and Treatment of Cancer to create a questionnaire for 34 rotationplasty patients who were more than a year from surgery and older than 16 years. They found that psychosocial functioning, general quality of life, and social support were comparable to healthy peers. Although almost half of the patients reported negative effects of the surgery on initiating social or intimate contact, body image, and sexuality, 64% of the patients had been sexually active in the month before the surgery.[20]

Other Rotationplasties

Although the focus of this review is rotationplasty about the knee, with the reversed ankle serving as a knee joint, it is important to note that other "rotationplasties" have been described. The knee rotationplasties described earlier are termed Winkelmann AI (distal femur and knee resection) and Winkelmann AII (knee and proximal tibia resection). Winkelmann also defined type B rotationplasties in which the knee serves as the hip joint, whereas the ankle functions as the knee joint.[21] Type BI and BII rotationplasties are performed after proximal femoral resection, the latter including an extra-articular resection of the acetabulum owing to hip involvement (Fig. 5). Finally, BIII-type rotationplasty is an operation in which the entire femur is resected (Fig. 6). Either the lateral tibial plateau is fashioned to form a pseudofemoral head and inserted into the acetabulum after rotation, or a hip hemiarthoplasty implant inserted into the rotated tibia is used to reconstruct the hip. Although these surgeries are less common than rotationplasty about the knee, good functional results and emotional acceptance have been reported.[22–24]

Conclusions

Rotationplasty remains an attractive limb-salvage option in the setting of lower-extremity sarcoma in the growing child. Rotationplasty can be a single surgery that provides a durable, highly functional extremity that functionally compares favorably with amputation and other limb-salvage techniques, while eliminating concerns for phantom pain, limb-length discrepancy, and endoprosthetic complications. Concerns of psychosocial well-being after rotationplasty do not seem to bear out in quality-of-life outcome studies, but highlight the need for patient and family education.

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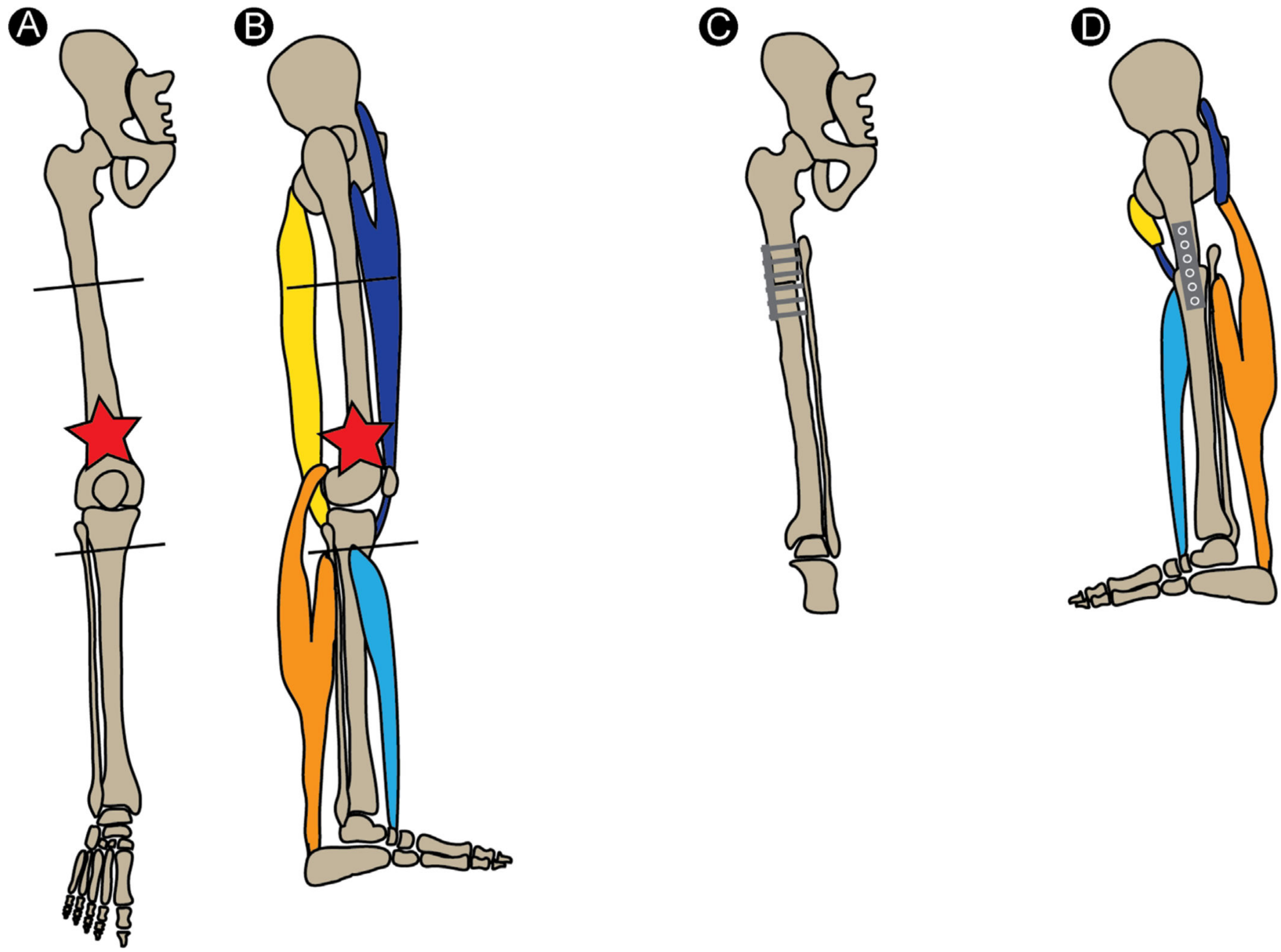

Figure 1.

Drawings representing rotationplasty for a distal femur tumor. (A) Anterior and (B) lateral views of a distal femur tumor (red star) with normal muscle groups noted in the lateral view. Black lines represent the approximate bone cut levels of a Winkelmann AI resection. (C) Anterior bone and (D) lateral bone and soft tissue views of the rotationplasty reconstruction showing the rectus femoris origin sutured to the gastrocnemius, and the hamstrings origins sutured to the extensor retinaculum of the proximal tibia. The ankle (now the knee) is still driven by normal ankle-driving muscles. (Key: royal blue = quadriceps, yellow = hamstrings, orange = gastroc or soleus, light blue = tibialis anterior.) (Color version of figure is available online.)

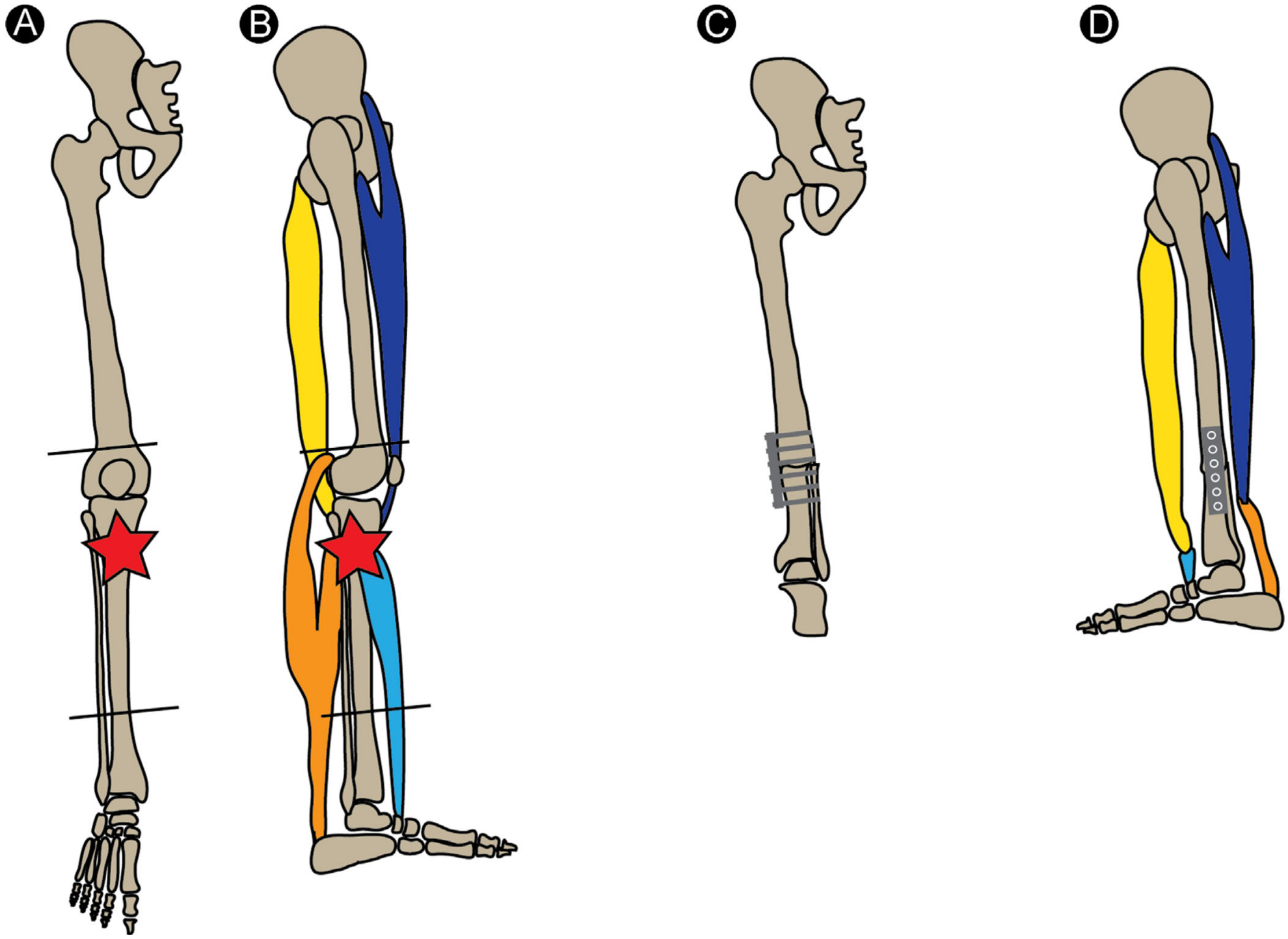

Figure 2.

Drawings representing rotationplasty for a proximal tibia tumor. (A) Anterior and (B) lateral views of a proximal tibia tumor (red star) with muscle groups shown in the lateral view. Black lines represent the approximate bone cut levels of a Winkelmann AII resection. (C) Anterior bone and (D) lateral bone and soft tissue views after rotationplasty reconstruction showing the quadriceps transferred to the Achilles tendon and the hamstrings transferred to the tibialis anterior tendon in the lateral view. Transferred thigh muscles drive the ankle (now the knee) function. (Key: royal blue = quadriceps, yellow = hamstrings, orange = gastroc or soleus, light blue = tibialis anterior.) (Color version of figure is available online.)

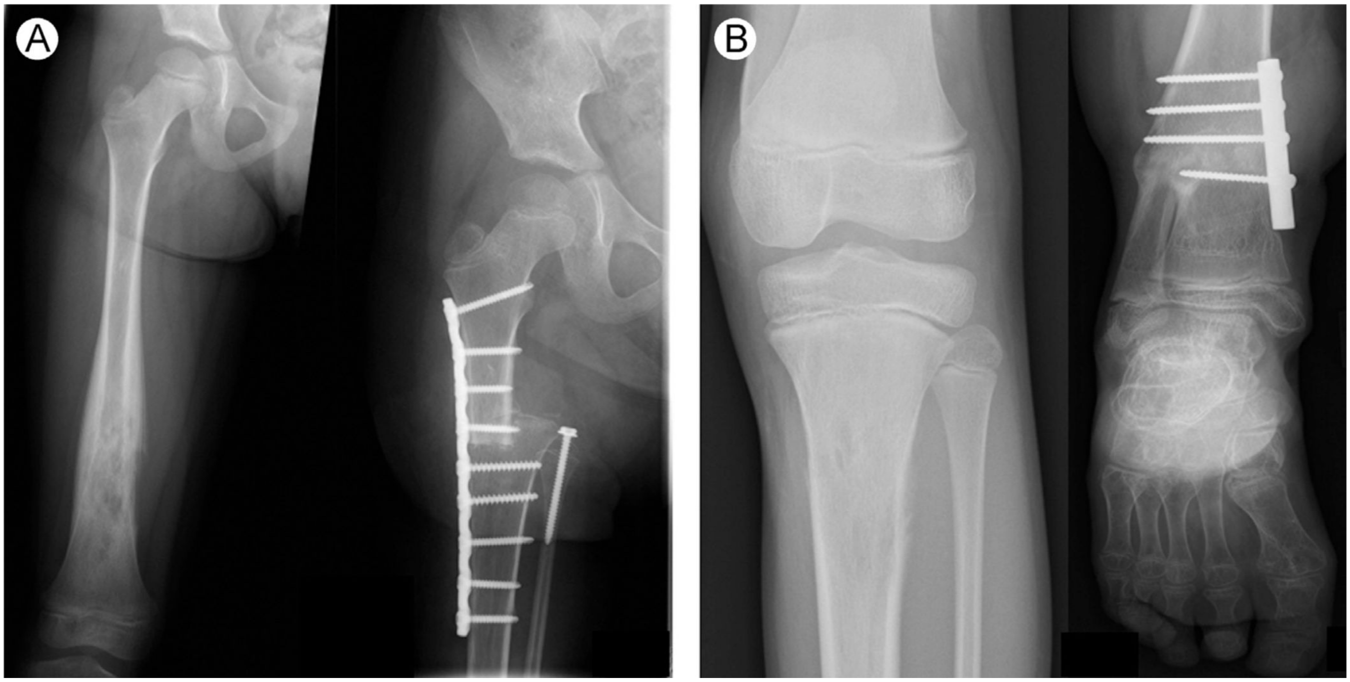

Figure 3.

Rotationplasty radiographs. Rotationplasty for tumors of the distal femur (A). Reconstruction is performed by removing the involved distal femur and a calculated amount of tibia to ensure at skeletal maturity, that rotated ankle joint is at the same level as the contralateral knee. Rotationplasty for tumors of the proximal tibia (B). These reconstructions can be more challenging as all vascular and nerve divisions distal to the knee must be identified and mobilized. The involved proximal tibia is resected, including a predetermined amount of distal femur. Small or large fragment compression plates can be used to stabilize the reconstructions. For short distal tibia and fibula fragments, both can be osteosynthesized with the distal femur metaphysis.

Figure 4.
Ankle (knee) function following tibial resection and rotationplasty. Clinical images of a rotationplasty reconstruction for a malignant tumor of the proximal tibia. Ankle dorsiflexion and plantar flexion, driven by transferred thigh muscles, now provides flexion and extension, respectively, of the new knee joint. (Color version of figure is available online.)

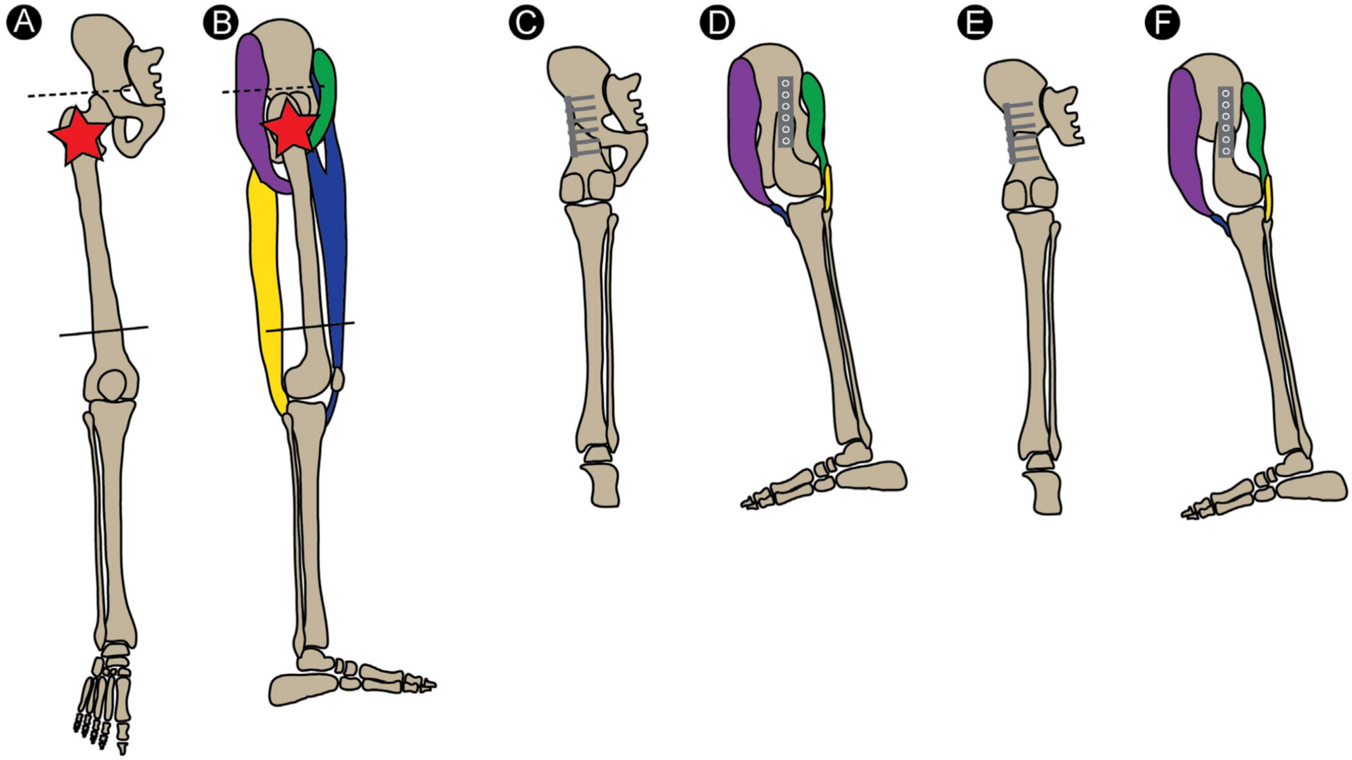

Figure 5.

Drawings representing rotationplasty for a proximal femur tumor. (A) Anterior and (B) lateral views of a proximal femur tumor (red star) with muscle groups shown in the lateral view. Black lines represent the approximate bone cut levels of Winkelmann BI and BII (also include the dotted line) resection. (C) Anterior bone and (D) lateral bone and soft tissue views after Winkelmann BI rotationplasty reconstruction showing the iliopsoas muscle transferred to the hamstring insertional tendons, and the gluteus maximus transferred to the patellar tendon in the lateral view. (E) Anterior bone and (F) lateral bone and soft tissue views after Winkelmann BII rotationplasty reconstruction after resection of the acetabulum. The same tendon transfers are used. (Key: royal blue = quadriceps, yellow = hamstrings, purple = gluteus maximus [hip extensor], green = iliopsoas [hip flexor].) (Color version of figure is available online.)

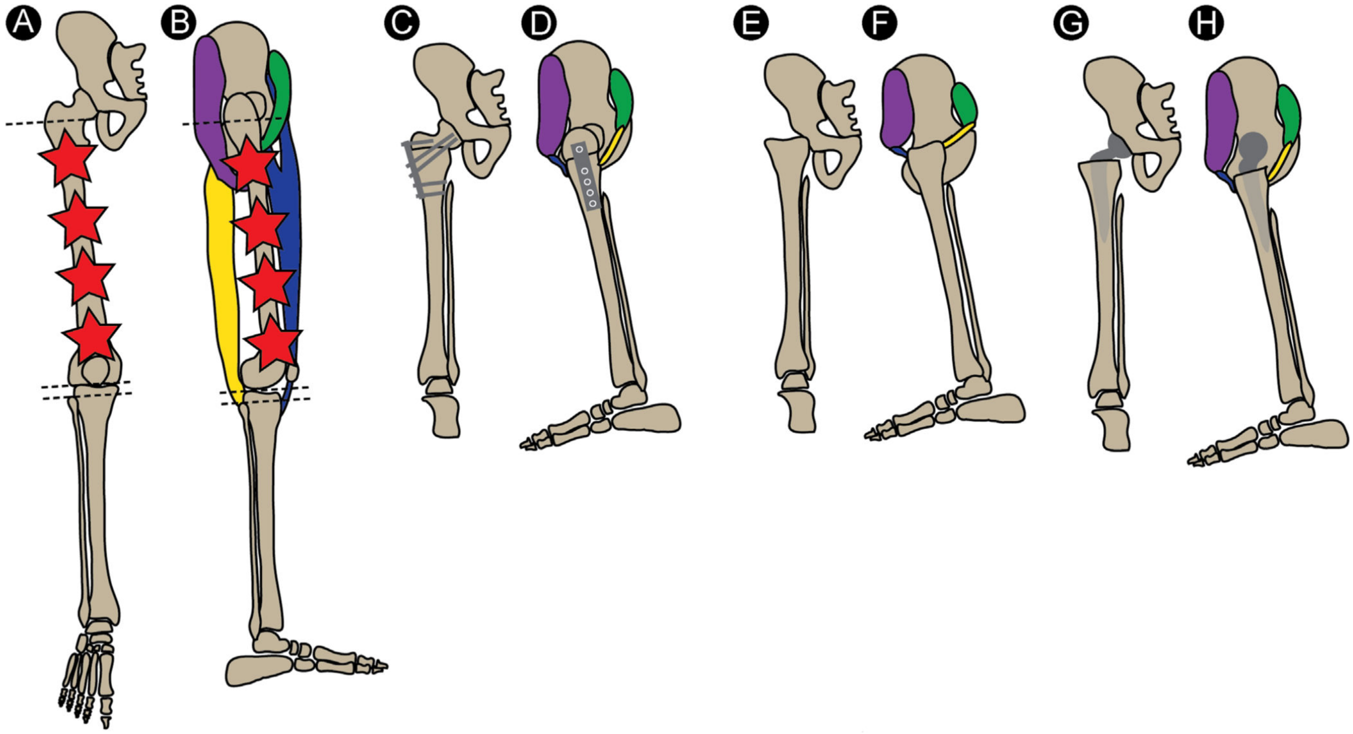

Figure 6.

Drawings representing rotationplasty for a full-length femur tumor. (A) Anterior and (B) lateral views of a long femur tumor (red stars) with muscle groups shown in the lateral view. Black dotted lines represent possible approximate bone cut levels for long femur resections (also include the dotted line) resection. (C) Anterior bone and (D) lateral bone and soft tissue views after a modified Winkelmann AI rotation plasty reconstruction with a minimal residual proximal femur, necessitating the iliopsoas muscle to be transferred to the hamstring insertional tendons, and the gluteus maximus muscle to be transferred to the patellar tendon in the lateral view. (E) Anterior bone and (F) lateral bone and soft tissue views after Winkelmann BIIIa rotationplasty reconstruction using the proximal tibia, inserted into the acetabulum as a hip reconstruction. The same tend on transfers are used. (G) Anterior bone and (H) lateral bone and soft tissue views after Winkelmann BIIIb rotationplasty reconstruction using a hemiarthroplasty implant, inserted into the tibia as a hip reconstruction. The same tendon transfers are used. (Key: royal blue = quadriceps, yellow = hamstrings, purple = gluteus maximus [hip extensor], green = iliopsoas [hip flexor].) (Color version of figure is available online.)