1 When and Why Biological/Implant Reconstruction?

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1.1 Principles of Limb Salvage Surgery

The main principle of treatment for bone and soft tissue tumors is to remove the tumor in its entirety. There are two main methods for achieving this goal [1–3]:

1. Amputation
2. Limb Salvage Surgery (LSS)

Amputation, which is a form of ablative treatment, removes the tumor-afflicted extremity at a safe level. When compared to LSS, it can be performed in a much shorter duration, is a relatively easier procedure, and can facilitate faster recovery. Nevertheless, it is a radical procedure and a valuable part of the body is lost forever. For all illnesses, especially for cancer, motivation is an important part of the patient's treatment process. This motivation is tremendously affected with the loss of a limb that comes with amputation. This, by itself, justifies the endeavor to salvage the limb.

Limb salvage surgery is the resection of the tumor with safe margins by including a cuff of healthy tissue while preserving the limb. The absolute requirement for attempting LSS is the probability of removing the tumor as safely as with an amputation. In addition to osseous or osteoarticular losses, resection may also involve sacrification of critical structures such as muscles, ligaments, skin, nerves, vessels, and/or neighboring organs. In a broad sense, the aim of subsequent reconstruction is to ensure integrity, viability, soft tissue coverage, and function of the limb. Despite the fact that reconstructive procedures are often the more intriguing and emphasized parts in LSS, reconstruction can never be considered apart from the resection. While an impressive and sophisticated reconstruction is likely to fail due to local recurrence in the setting of an inadequate resection, the patient's survival is also at stake with compromised margins. On the other hand, a carefully planned and skillfully executed resection in a well-selected patient will sometimes mandate a certain type of reconstruction or give more than one reconstructive option to the surgeon. Nevertheless, the resection is dependent on tumor-related (specific pathology, location, size) and patient-related (demographics) or treatment-related (previous invasive diagnostic/inappropriate procedures, response to neoadjuvant treatment) factors. Therefore, LSS is a total concept including all things done (or not done) starting from the time of presentation to the completion of reconstructive efforts and even the completion of adjuvant treatment. LSS is the mainstay of treatment today for most musculoskeletal malignancies and the treatment protocols have been standardized for common pathologies like osteosarcoma and Ewing's sarcoma in much of the developed world or the developing countries.

Van Nes rotationplasty is a very valuable intermediate surgical treatment method between amputation and LSS [2, 3]. When compared to amputation, it preserves significant function, avoids phantom limb pain, and results in less limb length discrepancy. However, cultural expectations, peculiar cosmesis, need for knowledge and experience of specific surgical technique, and the need for access to a skilled prosthetist limit its use.

In the light of this general perspective on amputation and LSS, the goals of treatment in musculoskeletal malignancies can be summarized and prioritized as:

1. saving the patient's life,
2. saving the limb,
3. preserving function of the limb,

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4. achieving good cosmesis of the limb,
5. compatibility of the treatment method with psycho-socio-cultural status of the patient.

The treating team must adhere to these priorities and carefully assess issues such as the required knowledge, skill, experience, technical resources, and presence of a specialist team for each case. Respecting these criteria in the appropriate order and informing the patient and/or the family explicitly about the objectives that can be achieved, it is almost always possible to avoid an ablative surgery today. The local control rate is shown to be similar for amputation and LSS in the era of advanced imaging and multimodal adjuvant treatment. The decision to perform a limb-sparing surgery or what kind of reconstruction to undertake in extreme cases, however, is a very individualized process, which should take into account the total impact of the planned procedure on the patient and the medical team in terms of health-related quality of life, economical burden, psychosocial effects, allocation of medical resources, and oncological risks [2–4].

Reconstruction in limb salvage surgery can be performed in two ways:

1. *Biological reconstruction*
   - Biological methods utilize materials, which are either living or have the capacity to revitalize and are obtained from either the patient (autograft) or from another person (allograft), to reconstruct the post-resection defect [5–11].
   - Distraction osteogenesis is also a very important, albeit less commonly used biological method in orthopedic oncology [12].
   - The definition of biological reconstruction may be extended to include hybrid methods (e.g., allograft/recycled autograft and prosthesis composites) and biological aspects of non-biological methods (e.g., bone lengthening in the setting of tumor prosthesis or bioexpandable prostheses) [5, 13].
2. *Implant (non-biological) reconstruction*
   - Tumor prostheses or megaprostheses are the main instruments of non-biological defect reconstruction [14, 15].
   - Bone cement is also a very versatile non-biological material, which can be used with tumor prostheses or osteosynthesis implants for defect reconstruction.
   - Non-biological methods may harbor biological components (e.g., graft/prosthesis composites or bioexpandable parts) as also mentioned for biological methods [5, 13].

1.2 When and Why Biological Reconstruction?

The main advantage of biological reconstruction is that when the healing process is complete, the reconstruction material becomes totally incorporated into the patient's body [5–11]. The biologically reconstructed segment, which either maintains its vitality and thus unites with the recipient site or regains its vitality by creeping substitution after uniting with the recipient site, eventually becomes the patient's own. The living nature of the healed segment gives it responsive capability so that it can remodel, heal if it is fractured or hypertrophy under weight-bearing conditions (Fig. 1.1). Therefore, biological reconstruction offers a potentially life-long limb salvage solution, which even facilitates safe participation in recreational activities in survivors of musculoskeletal malignancies.

Biological reconstruction reduces soft tissue problems through three different mechanisms. Biological materials occupy less space (Fig. 1.2), allows adherence of soft tissues onto their surfaces, and also may bring their own soft tissue cover as in an osteo-myofasciocutaneous flap. Hence, wound problems and secondary deep infections are less commonly encountered. Furthermore, early postoperative complications such as infected hematoma can be effectively treated. If the healing of biological reconstruction fails partially, as would be the case in the setting of mechanical insufficiency while the graft's vitality is preserved, complications like graft fracture or nonunion might occur and yet can be treated by revision of osteosynthesis as in a normal fracture (Fig. 1.3). Limb length discrepancy can be managed in the same way as in a non-oncological setting (Fig. 1.4). If, however, biological potential has been lost or cannot be regained in a reasonable time, the reconstructed segment might end up as dead bone and fail totally due to deep infection and/or resorption. Biological reconstruction has the advantage of possible conversion to implant reconstruction even in this worst-case scenario (Fig. 1.5).

While biological methods yield durable reconstructions with relatively less morbid and biologically manageable complications, the major disadvantage is the substantially long healing time, which particularly causes problem regarding lower extremity reconstructions due to prolonged period of restricted weight-bearing (Fig. 1.6). These limb salvage considerations are most compatible with a patient who has a high likelihood of survival and thus can afford to wait for the lengthy healing period. This, in turn, depends on the presence of good prognostic factors such as being non-metastatic at presentation, showing a good neoadjuvant treatment response, not having a large tumor and not having sustained a pathological fracture.

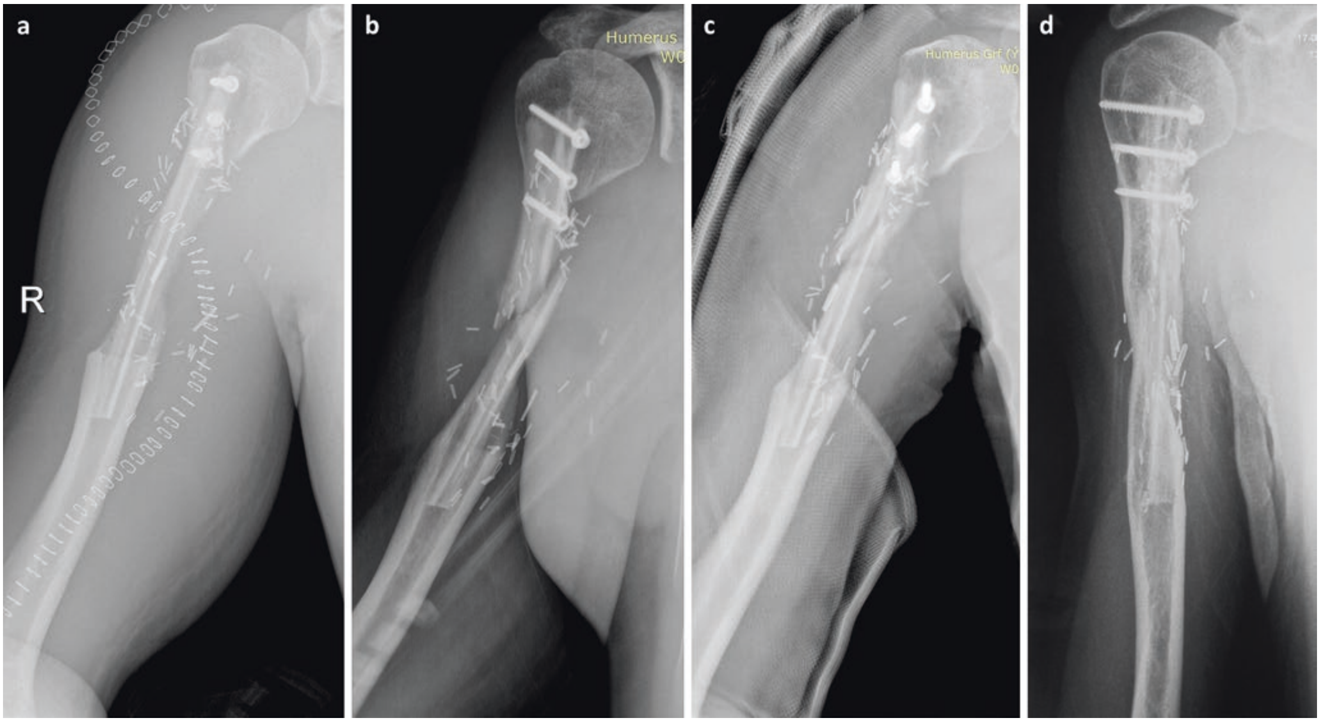


Fig. 1.1 Early postoperative radiograph demonstrates intercalary biological reconstruction following resection of proximal humerus chondrosarcoma in a 35-year-old-male patient (**a**). The patient presented with fracture of the vascular fibula graft at postoperative 3 months (**b**). The fracture was conservatively managed following closed reduction (**c**). Follow-up radiograph at postoperative 7 years shows excellent remodeling after fracture healing (**d**). The case is an excellent example of how biological reconstruction allows simple and effective management of limb salvage complications

On the other hand, certain disadvantages associated with implant reconstruction, such as loss of joint surfaces, loss of physeal plates on both sides of the joint, and loss of bone stock, which could actually be spared, make biological reconstruction with intercalary resection the treatment of choice for some cases or a necessity in others. The feasibility of a safe intercalary resection is closely related with radiological findings. An interim radiological evaluation may be reasonable in cases, for which biological reconstruction is planned. For example, a magnetic resonance imaging (MRI) examination performed after the second cycle of a “3-cycle neoadjuvant chemotherapy” may demonstrate whether if radiological response is good and therefore intercalary resection is safe or if there is tumor progression and an endoprosthetic reconstruction will be safer. Thus, the reconstruction strategy may be worked out before final preoperative MRI. Which MRI parameters should be used to determine surgical margins are open to debate. While the safest margins can be accepted as those determined according to pre-chemotherapy short tau inversion recovery (STIR) or turbo inversion recovery magnitude (TIRM) sequences on MRI, the margins most encouraging for intercalary resection, are those determined according to post-chemotherapy contrast-enhanced sequences in a good-responder. As a general rule, the surgical margins are determined according to radiology at presentation for osteosarcoma and according to follow-up imaging after neoadjuvant treatment for Ewing’s sarcoma since chemosensitivity and radiosensitivity are thought to play a bigger role in local tumor control in the latter pathology.

Although more rarely performed, biological reconstruction may also play an important role after intraarticular resection in small children (Fig. 1.7) and particularly in the upper extremity. Long-term complications of implant reconstruction, such as periprosthetic infection, inevitable need for revision, and continuing loss of bone stock, also bring forth biological reconstruction as the method of choice, in younger patients, particularly in the skeletally immature.

Biological reconstruction might be considered economically advantageous when compared to implant reconstruction in general. While this advantage may vary according to specific method of biological reconstruction used, harvesting a non-vascular structural bone graft has virtually no cost and recycling techniques, such as liquid-nitrogen cryotreatment, autoclaving, and pasteurization, also have minimal economic impact and demand minimal resource and equipment. While microsurgical reconstruction with a vascular bone flap is a

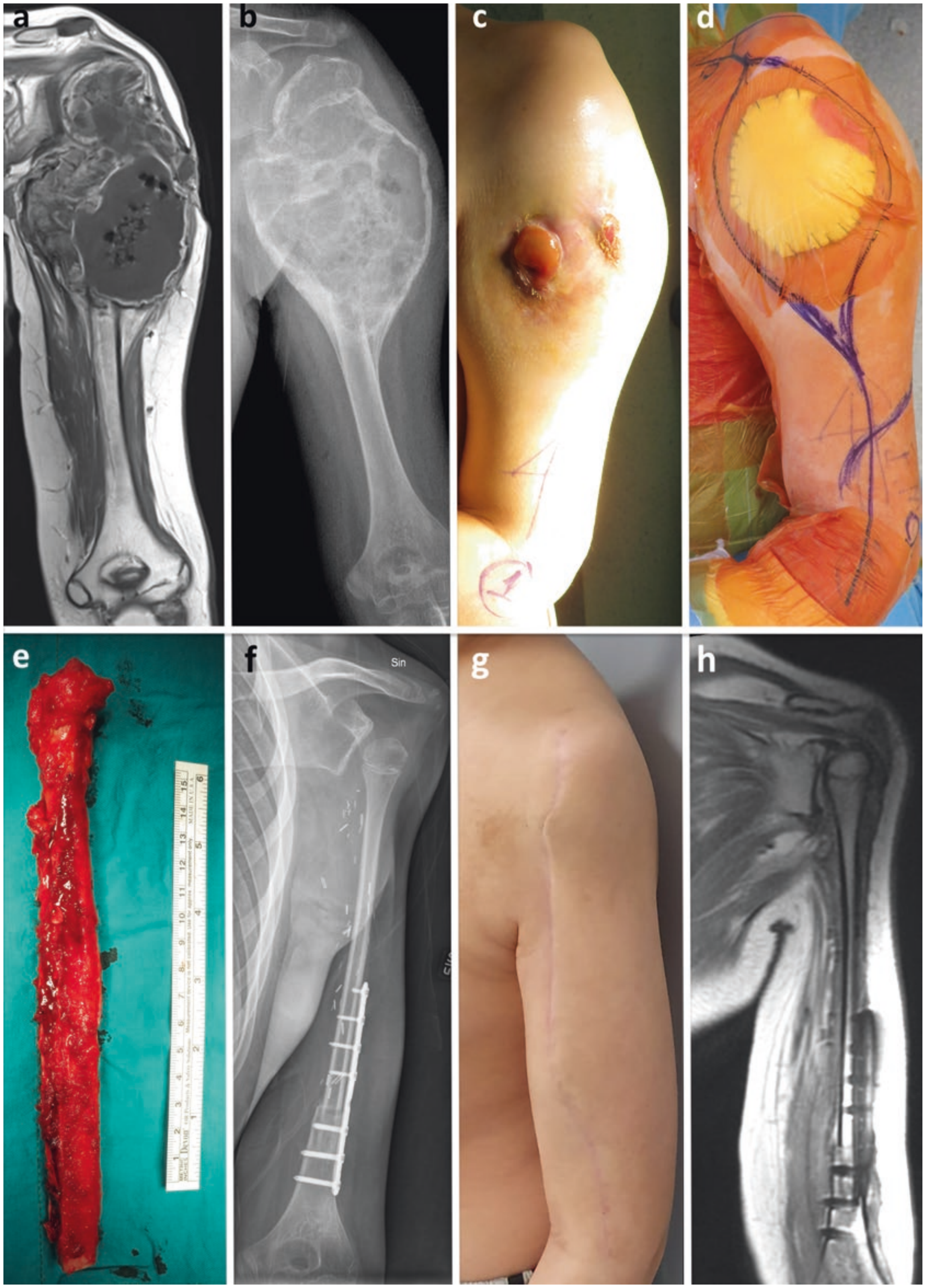


Fig. 1.2 The MRI section, the radiograph, and the clinical photo demonstrate an exulcerated telangiectatic osteosarcoma of the proximal humerus in a 12-year-old non-metastatic male patient (**a**–**c**). MRI shows extensive tumor necrosis following neoadjuvant chemotherapy (**a**). Wide intraarticular resection was performed including the exulcerated part (**d**). Free vascular fibular graft with proximal epiphysis was used for biological reconstruction of the humerus (**e**). Despite significant skin and subcutaneous tissue sacrification, the relatively small volume occupied by the fibula graft, in comparison to tumor prosthesis, facilitated excellent primary soft tissue coverage (**f**–**h**)

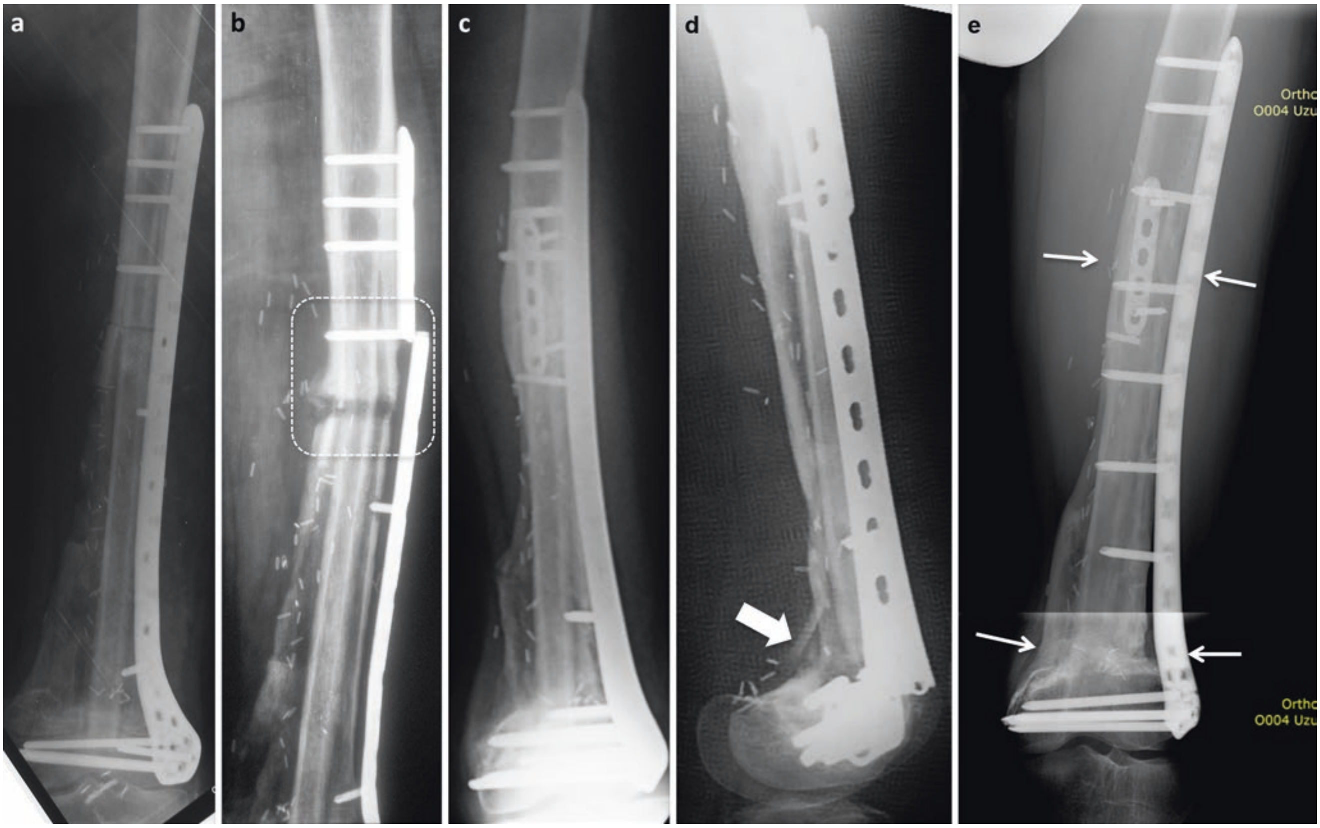


Fig. 1.3 Early postoperative radiograph demonstrates "frozen hotdog" (liquid nitrogen recycled autograft shell & inlaid vascular fibula combination) reconstruction in a 14-year-old-male patient with distal femur osteosarcoma (**a**). Delayed union of the shell resulted in graft fracture and implant failure in the proximal osteotomy site at postoperative 9 months (**b**) and in the distal osteotomy site at postoperative 24 months (**d**). Image taken from standing AP orthoroentgenogram at 4 years shows that full consolidation of the hotdog segment was finally achieved after two revision surgeries (**c**, **e**). The final radiological outcome confirms that biological activity was preserved, most probably due to inlaid vascular fibula. Mechanical failures of biological reconstruction can be treated in similar fashion to normal fracture complications as long as there is "sufficient" biological potential

time, resource, and effort demanding procedure, it can still be considered as a relatively low-cost treatment if utilized in a specialized center setting where the procedure is being performed routinely by a dedicated microsurgery team. The availability of a national bone bank might also favor massive allograft use as a more economical option compared to implant reconstruction. Finally, the long-term solution provided by biological reconstruction also eliminates the costs of future implant revisions.

In the light of these treatment concerns, biological reconstruction may be best indicated in a younger patient with good prognostic factors and a tumor suitable for safe intercalary resection (Figs. 1.8 and 1.9). Wound problems are better prevented or managed with biological reconstruction. While economic factors should not be cited as a criterion for determining the best treatment strategy, they often emerge as a reality of medical procedures and biological methods offer serious advantages to implant reconstruction.

1.3 When and Why Implant (Non-biological) Reconstruction?

Advanced design features of modern-day implants facilitate near-normal biomechanics especially around the knee joint, which frequently undergoes non-biological reconstruction in the oncological setting [14, 15]. Furthermore, the modularity of most megaprosthetic systems used today allows the surgeon to precisely adjust the extremity length and rotation and to modify the reconstruction plan intraoperatively [14, 15]. These aspects provide great comfort for both the patient and the surgeon. Taking into account the good function and the relative ease of application, implant reconstruction should be considered as the treatment of choice when the joint surface cannot be salvaged due to tumor invasion or proximity and an intraarticular (or extraarticular) resection is warranted. While epiphyseal tumor involvement in MRI is not an absolute indication for

Fig. 1.4 Anteroposterior standing orthoroentgenogram of a 20-year-old-male patient shows leg length discrepancy of 8 cm in the left lower extremity 9 years after “frozen hotdog” (liquid nitrogen recycled autograft shell & inlaid vascular fibula combination) reconstruction of the left femur due to osteosarcoma (**a**, **b**). Following plate removal, lengthening of 4 cm was performed with an intramedullary motorized magnetic nail (**c**–**f**). The procedure was performed in a very similar fashion to lengthening in a non-oncological setting

intraarticular resection, plain infiltration of the joint cartilage, extension into the joint space or extension over the ligaments, and joint capsule mandate an intraarticular (or extraarticular) resection (Figs. 1.10, 1.11, 1.12 and 1.13).

Implant reconstruction offers the main advantage of almost immediate or at least faster recovery of functions depending on anchorage properties, such as the use of cemented or cement-less stems, and any associated soft tissue reconstruction. Similarly, early weight-bearing can often be allowed in the lower extremity in stark contrast to biological reconstruction. Therefore, the healing time is substantially shorter for implant reconstruction than that of biological reconstruction. Patients with bad prognostic factors such as being metastatic at presentation, showing a bad neoadjuvant treatment response, having a large tumor, and having sustained a pathological fracture should be very carefully assessed for biological reconstruction and must strongly be considered for implant reconstruction since the prognosis is often incompatible with the prolonged healing expected in biological methods (Fig. 1.14). Although pediatric patients tolerate and function very well with implant reconstruction especially around the knee, biological reconstruction is reserved as the primary option for them due to above-mentioned reasons. Nevertheless, implant reconstruction should be favored particularly in adults with lower extremity tumors due to their relatively diminished bone healing capacity, increased body weight, and time constraints related to going back to work and other daily activities. Consequently, an adult patient with bad prognostic factors and a lower extremity tumor where the joint is non-salvageable is the ideal candidate for implant reconstruction.

An important yet debatable indication for implant reconstruction might be not having the surgical skill, experience, infrastructure, and organization to perform a biological reconstruction where an intercalary resection might be considered. The orthopedic oncologist might not be familiar with the biological method(s); a microsurgeon and/or necessary operation room setting for microsurgery, equipment, and facilities required for bone recycling or bone bank for allograft use might not be available. Furthermore, tumor destruction may render the bone useless as a recycled autograft, the patient might not accept any donor-site morbidity ruling out any graft/flap harvest, and the patient may not allow the use of cadaveric bone

Fig. 1.5 Post-chemotherapy MRI shows good radiological response in an 11-year-old non-metastatic male patient with distal femur osteosarcoma extending into the epiphysis at presentation (**a**). Intercalary (intraepiphyseal) resection and biological reconstruction with "frozen hotdog" (liquid nitrogen recycled autograft shell & inlaid vascular fibula combination) technique was performed (**b**, **c**). Despite full consolidation of the hotdog segment, local recurrence was detected in the epiphysis of the medial condyle at postoperative 38 months (**d**, **e**). Despite local recurrence, a second attempt at limb salvage was successful with resection of the biologically reconstructed segment following preoperative radiotherapy and implant reconstruction of the distal femur (**f**, **g**)

grafts due to sociocultural and/or religious reasons. Patients might also reject biological reconstruction due to concerns about oncological safety of bone recycling methods or viral disease transmission risk associated with fresh frozen massive allografts. In such cases, the most biological approach for an implant reconstruction must be sought. If, for example, intercalary resection can be performed, the joint might be salvaged and an intercalary diaphyseal endoprosthesis might be implanted.

1.4 The Gray Zone

Some cases of musculoskeletal tumors fall into a gray zone with regard to whether a limb salvage surgery can be performed or not, before any discussion of whether biological or implant reconstruction is better indicated. A huge exulcerated tumor or one with imminent skin breakdown, neurovascular involvement, and anticipation of significant soft tissue defect are common features. These cases, especially if they are skeletally immature, might actually be good candidates for Van Nes rotationplasty. However, psycho-sociocultural incompatibility may exclude rotationplasty in some cases.

Yet for other cases in the gray zone, the indication for limb salvage surgery might be a definite one but the decision to perform a biological or implant reconstruction is difficult with regard to oncological safety and possible critical gains with the biological method. In certain cases, neither method is clearly the better choice. In those cases, the patient's and the treating team's preferences are decisive. In rarer cases, when a significant advantage or dramatic difference in treatment outcome is anticipated, riskier and unconventional solutions might be sought

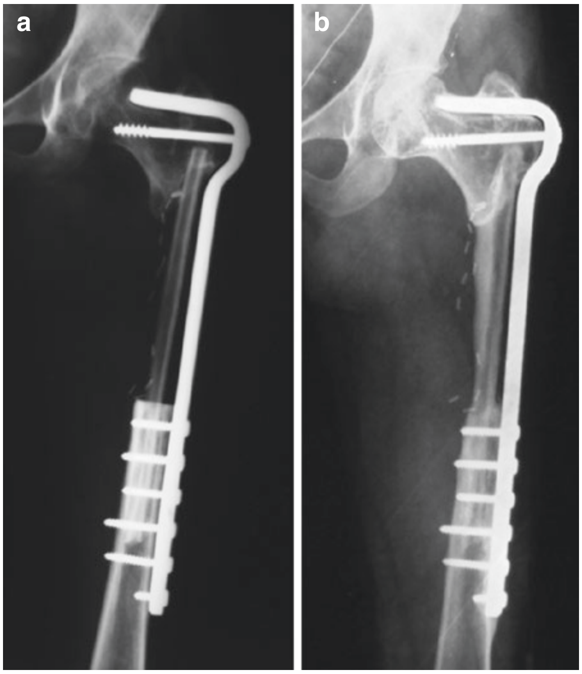


Fig. 1.6 Anteroposterior femur radiographs at early postoperative period (**a**) and at 4 years (**b**) demonstrate the *moderate* amount of *hypertrophy* in a single barrel vascular fibula graft, which was utilized for intercalary reconstruction of the proximal femur in a 15-year-old-female patient with Ewing's sarcoma. Despite good oncological and functional outcome, the patient had to wait for a prolonged period of time for full weight-bearing due to risk of graft fracture

instead of conventionally accepted methods. There are certain prerequisites, however, to implement such unconventional methods. Any intended reconstructive gain must not breach the principles of safe resection and compromise local control under any circumstance. Tailoring the chemotherapeutic regimen according to interim clinical and radiological evaluations, preoperative use of radiotherapy or concomitant chemoradiotherapy (even in not very sensitive tumors like osteosarcoma) (Figs. 1.15 and 1.16), special resection techniques (Figs. 1.17, 1.18, and 1.19), advanced neurovascular reconstruction, and extensive use of both local and free flaps (Fig. 1.20) can all be used to "safely modify" the surgical margins rather than violating them [16–21]. For these reasons, such unconventional procedures should only be undertaken by a competent and experienced multi-disciplinary team in a specialized orthopedic oncology center, which can provide the necessary technical resources, after an extensive discussion with the patient regarding all options, risks, and possible complications.

Provided that all aspects of limb salvage surgery are under control, such "innovative" and "extraordinary" procedures offer prospective benefits in terms of function, complications, and oncological outcome. Even if the long-term outcome is not excellent for a specific limb salvage procedure, preserved joint or bone stock might pave the way for conver-

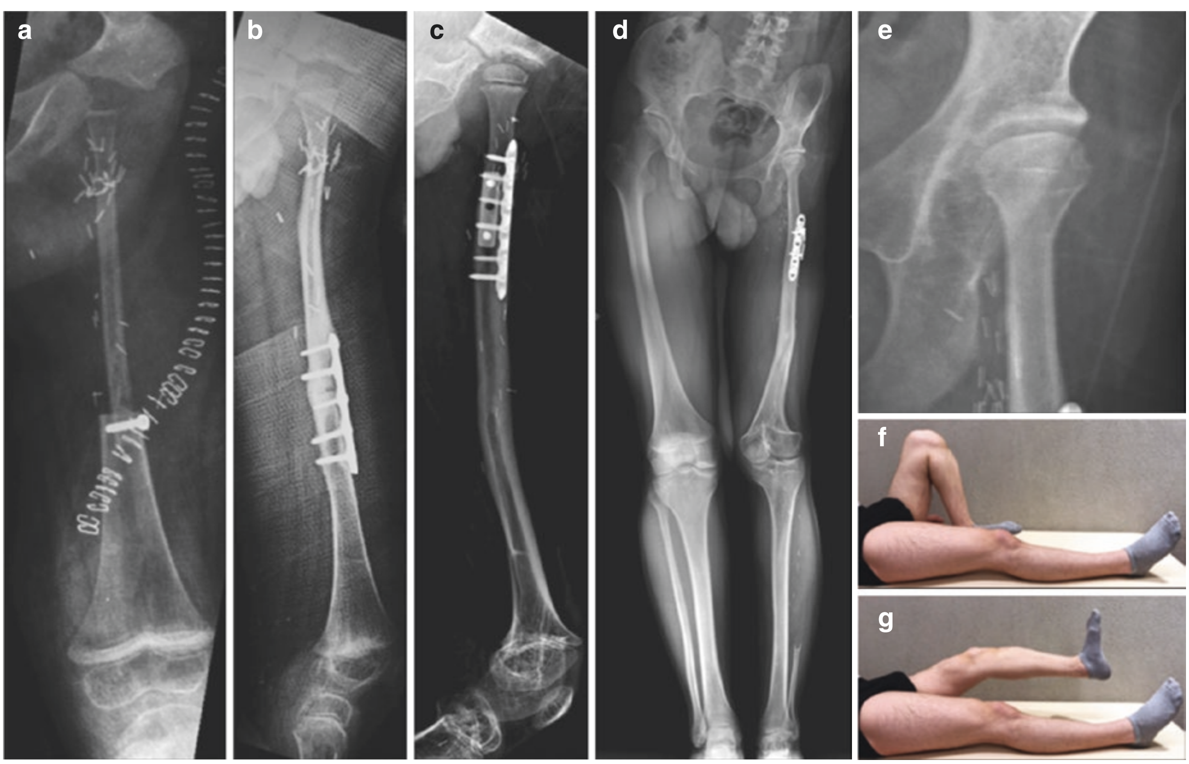


Fig. 1.7 Early postoperative femur radiograph (**a**) demonstrates intraarticular biological reconstruction of the proximal femur using free vascular fibular graft with the proximal epiphysis in a 4.5-year-old non-metastatic male patient with osteosarcoma. Consecutive radiographs at postoperative 2, 6 and 12 years (**b**–**d**) demonstrate healing and hypertrophy of the fibula despite several graft fractures and osteosynthesis revisions over the years. The fibular head has strikingly remodeled as the new femoral head (**e**). While there is a leg length discrepancy of approximately 10 cm, which needs to be addressed, the hip function is excellent given the non-anatomical characteristic of the reconstruction method (**f**, **g**)

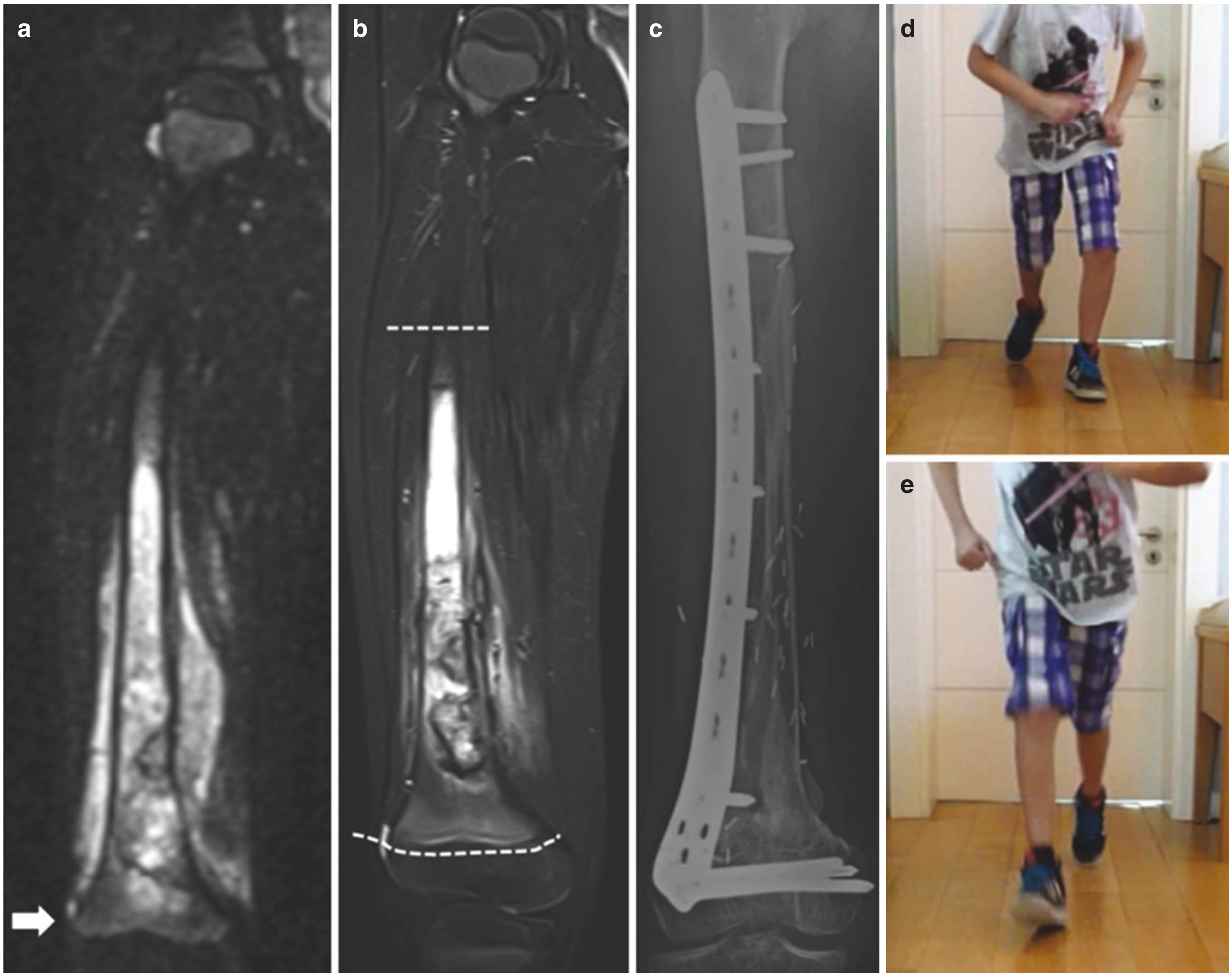


Fig. 1.8 Coronal MRI section demonstrates a distal femur osteosarcoma involving the metaphysodiaphyseal region in a 9-year-old non-metastatic male patient at presentation (**a**). Note that the tumoral involvement is sharply limited by the physeal plate with regard to both the bone and the soft tissues (white solid arrow). MRI following neoadjuvant chemotherapy shows good radiological response with regression of the soft tissue component, regression of bone marrow edema, and demarcation of the osseous lesion (**b**). The anatomical features, the treatment response, and the patient's age indicate an ideal candidate for intercalary biological reconstruction. An intercalary resection with safe margins is possible with careful and skillful execution. White dashed lines show the planned proximal (diaphyseal) and distal (juxtaphyseal through the epiphysis) osteotomy sites. On the contrary, an intraarticular resection with distal femur endoprosthetic reconstruction will result in loss of patient's own knee joint, loss of bone stock in the proximal femur due to stem insertion, loss of proximal tibial physis, and will cause significant limb length discrepancy unless a growing prosthesis, which in turn has its own potential complications, is implanted. Anteroposterior femur radiograph (**c**) and still images taken from a running video of the patient at postoperative 24 months (**d**, **e**) show excellent radiological and functional outcome after "frozen hotdog" (liquid nitrogen recycled autograft shell & inlaid vascular fibula combination) reconstruction

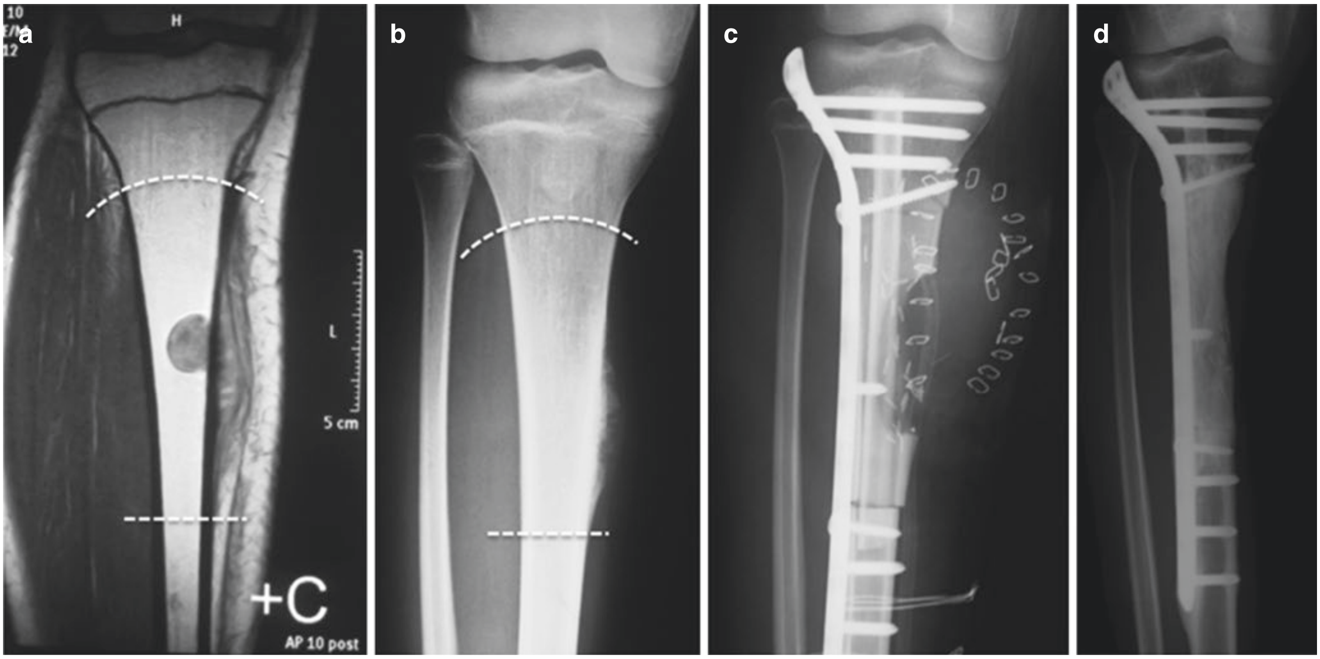


Fig. 1.9 The coronal MRI section and the plain radiograph show the tumoral involvement in the proximal tibial diaphysis of a 14-year-old non-metastatic female patient with Ewing's sarcoma (**a**, **b**). White dashed lines represent the planned osteotomy sites for intercalary resection. The tumor volume is relatively small and the lesion is relatively far from the joint, making an intercalary resection safe and feasible. Early postoperative radiograph shows biological reconstruction with "frozen hotdog" (liquid nitrogen recycled autograft shell & inlaid vascular fibula combination) technique (**c**). The surgical staples indicate a skin-grafted area over medial gastrocnemius flap. Radiograph at postoperative 8 years shows fully consolidated hotdog segment (**d**)

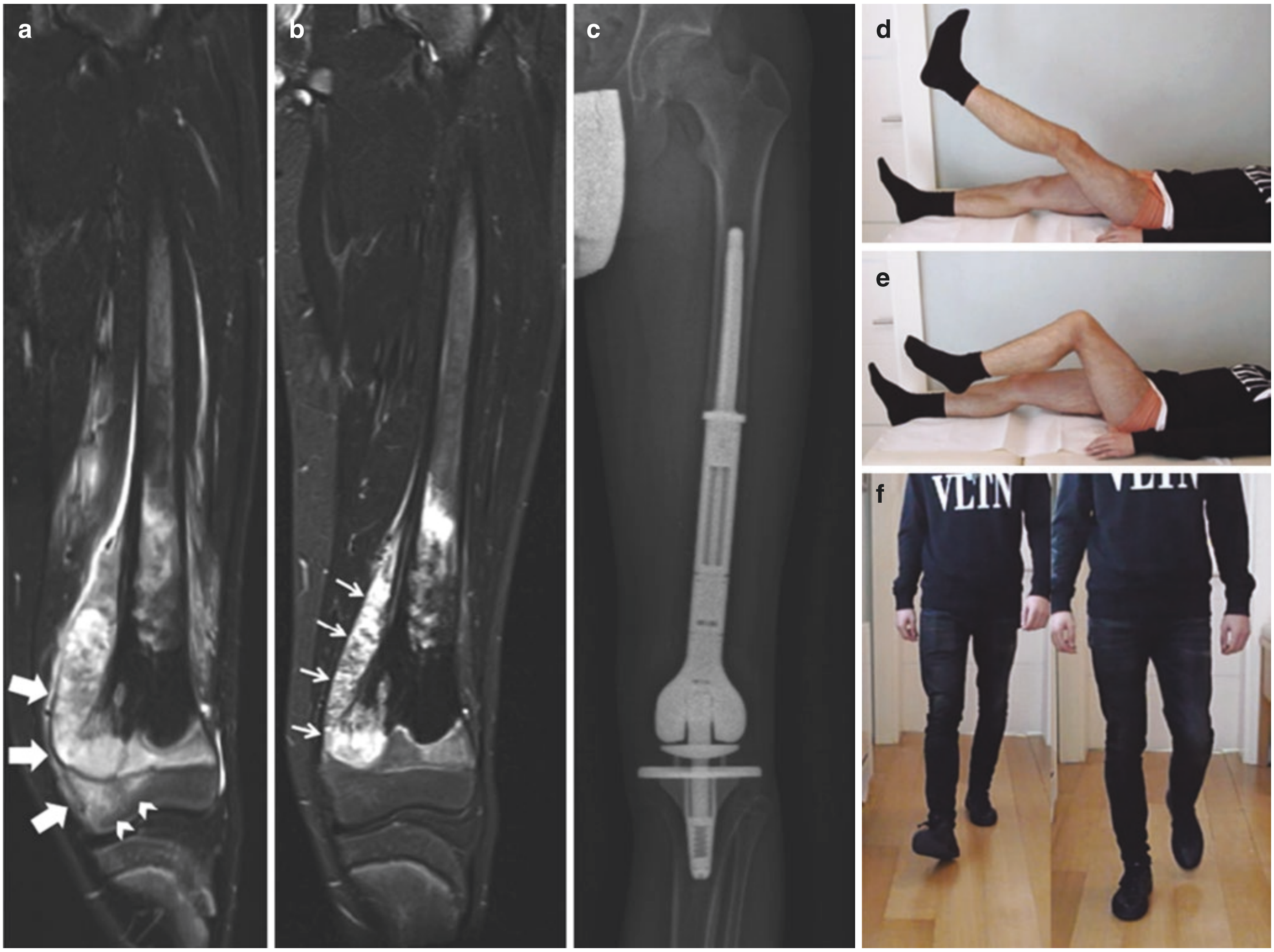


Fig. 1.10 Coronal MRI at presentation demonstrates a distal femur osteosarcoma involving the metaphysodiaphyseal region in a 14-year-old-male patient (**a**). Note that there is suspicious tumoral extension distally into the epiphysis of the medial femoral condyle reaching the subchondral bone (white chevrons) and also over the soft the tissues beyond the perichondrium (white solid arrows). Although suspicious osseous and soft tissue involvement of the medial part of the epiphysis has regressed in the MRI following neoadjuvant chemotherapy, the soft tissue component on the metaphysodiaphyseal region (white arrows) has responded only moderately (**b**). Classic knowledge for surgical margins in osteosarcoma dictates that the resection must be planned according to MRI findings at presentation and therefore an intercalary resection is neither safe nor feasible in this case. Furthermore, a less pronounced limb length discrepancy (LLD) might be anticipated with the loss of physes around the knee due to the patient's age. Postoperative radiograph shows reconstruction with distal femur replacement prosthesis (**c**). Acute lengthening of 2 cm was performed during implant reconstruction in this patient to minimize expected LLD. Clinical photos at postoperative 4 years show good active knee range of motion (**d**, **e**), while still images taken from a walking video show completely normal ambulation (**f**)

Fig. 1.11 The coronal MRI and the AP radiograph demonstrate tumoral involvement of the proximal tibial metaphysis and epiphysis, extending across the joint cartilage, joint capsule, and ligaments into the knee joint in a 21-year-old non-metastatic male patient with osteosarcoma (**a**, **b**). Salvage of the joint was not possible. Furthermore, the patient, who operated heavy machinery, expressed his desire to return to work as soon as possible. A modified extraarticular proximal tibia resection (including all intraarticular and periarticular soft tissues of the knee joint) was performed following neoadjuvant chemotherapy (**c**, **d**). While the standing anteroposterior orthoroentgenogram shows implant reconstruction of the proximal tibia (**e**), clinical images at postoperative 5 years (**f**–**h**) demonstrate excellent function of the patient, who returned to work right after the adjuvant chemotherapy was over

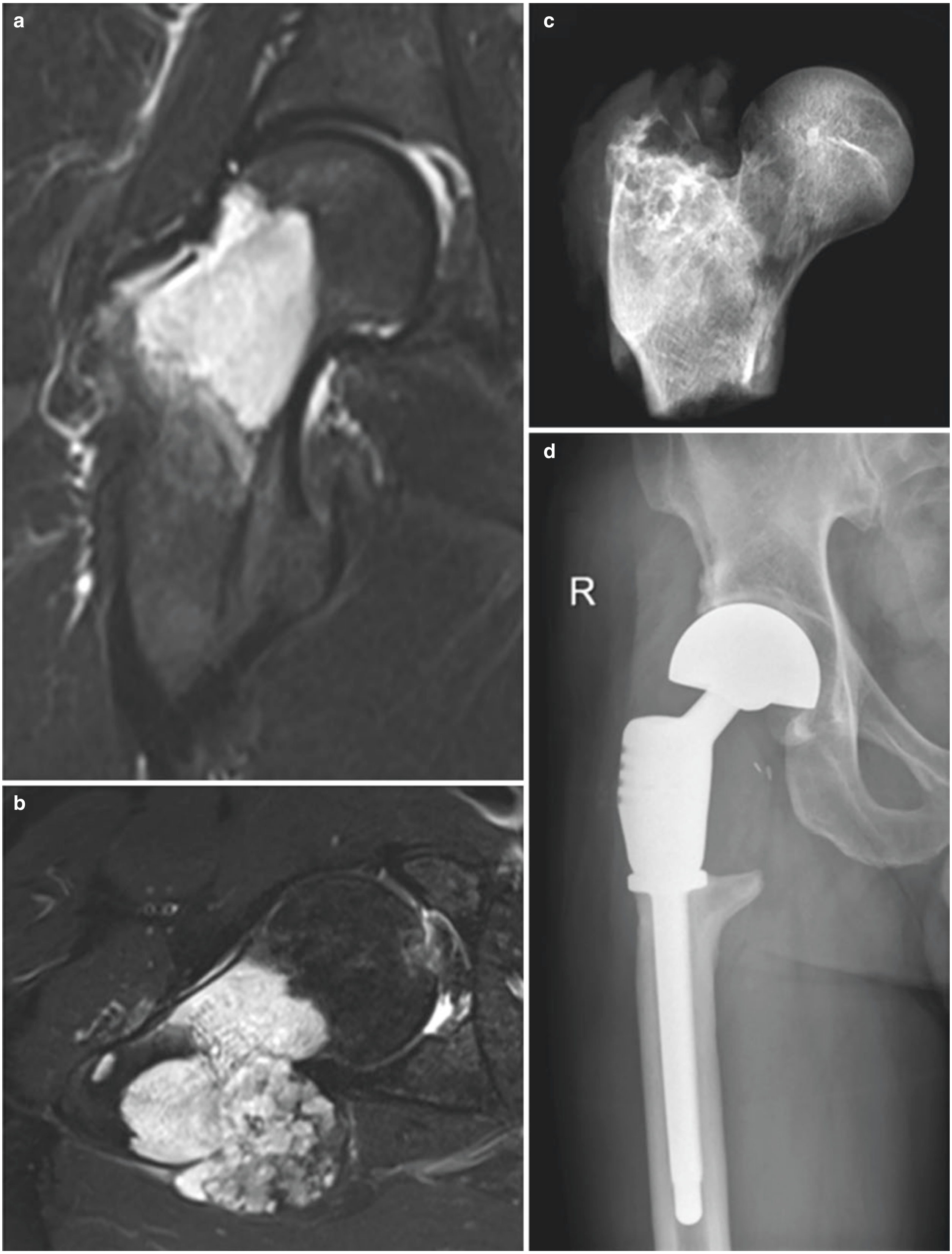


Fig. 1.12 Coronal and axial MRIs demonstrate Grade II chondrosarcoma of the proximal femur in a 48-year-old-male patient (**a**, **b**). The tumor location and the patient's age rule out any attempt to salvage the femoral head with the intent of biological reconstruction. Wide intraarticular resection (**c**) followed by implant reconstruction of the proximal femur (**d**) was performed for oncological safety and to allow immediate ambulation with full weight-bearing

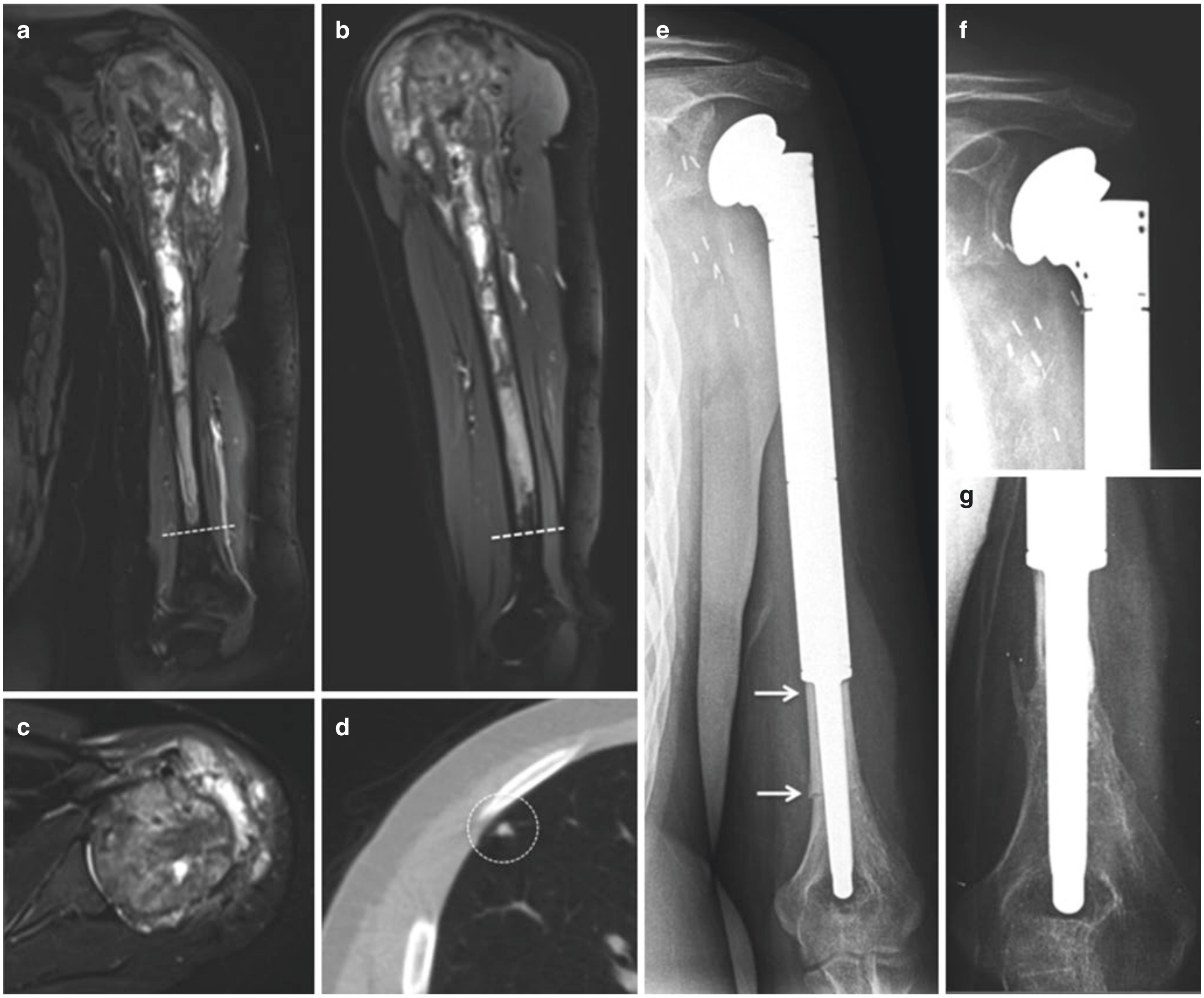


Fig. 1.13 Post-chemotherapy coronal and axial MRIs demonstrate proximal humerus osteosarcoma with poor response and extensive intramedullary involvement in a 27-year-old-male patient (**a**, **b**). The extent of tumoral involvement in the humeral head ruled out any joint salvage attempt (**a**–**c**). Thorax CT scan also revealed a nodule, which was consistent with pulmonary metastasis (**d**). Wide intraarticular resection and reconstruction with cement-less tumor prosthesis was planned. White dashed lines in **a** and **b** represent the proposed site of distal osteotomy. However, the remaining bone segment in the distal humerus was too short to accommodate the prosthesis stem. This problem was overcome by using the liquid-nitrogen recycled distal diaphyseal segment (white arrows) to augment primary stability of the stem and to increase bone–prosthesis interface for osseointegration (**e**). Radiographs at postoperative 15 months show stable glenohumeral joint (**f**) and excellent stem stability with complete fusion of the recycled segment despite some resorption (**g**). The patient was lost due to pulmonary metastases at 2 years postoperatively without any incident in his salvaged limb

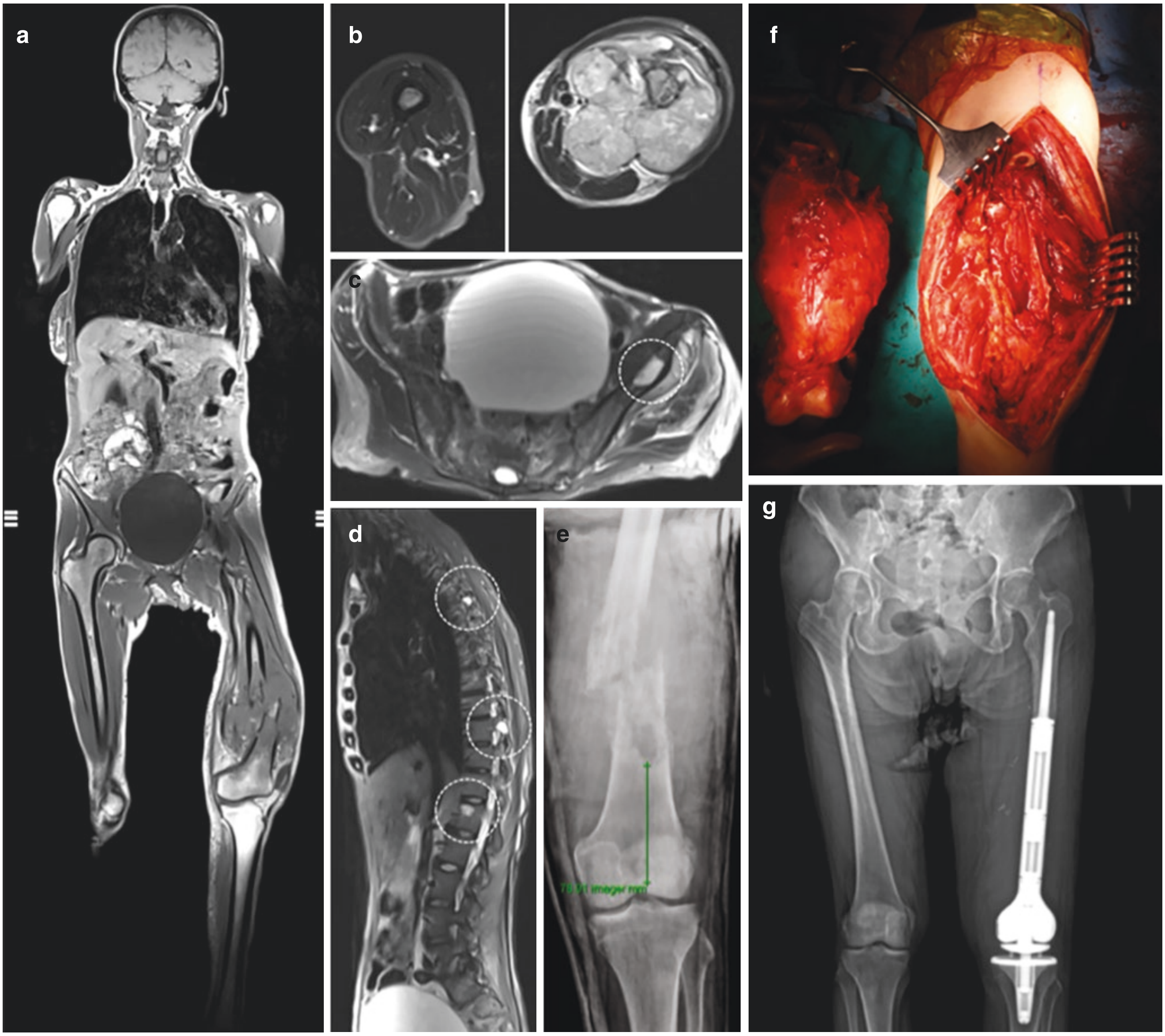


Fig. 1.14 Coronal whole-body MRI section demonstrates a pathological femur fracture in a 58-year-old-female patient with known history of endometrium carcinoma (**a**). Whole-body MRI also revealed multiple bone metastases in the pelvis and spine (**b**–**d**). Treatment objectives were determined as pain management and to facilitate immediate mobilization to allow continuation of other oncological treatments. Non-biological reconstruction with tumor prosthesis was planned. Remaining distal healthy bone stock was measured to entertain the possibility of joint salvage with intercalary tumor prosthesis (**e**). However, intraarticular resection with distal femoral replacement was deemed more reliable in terms of anchorage Intraoperative image shows the resected segment involving the distal femur articular surface (**f**). Postoperative radiographs show the distal femoral endoprosthetic reconstruction, which allowed immediate ambulation of the patient (**g**). She was lost due to widespread carcinoma mestastases at 9 months postoperatively without any incident in her salvaged limb

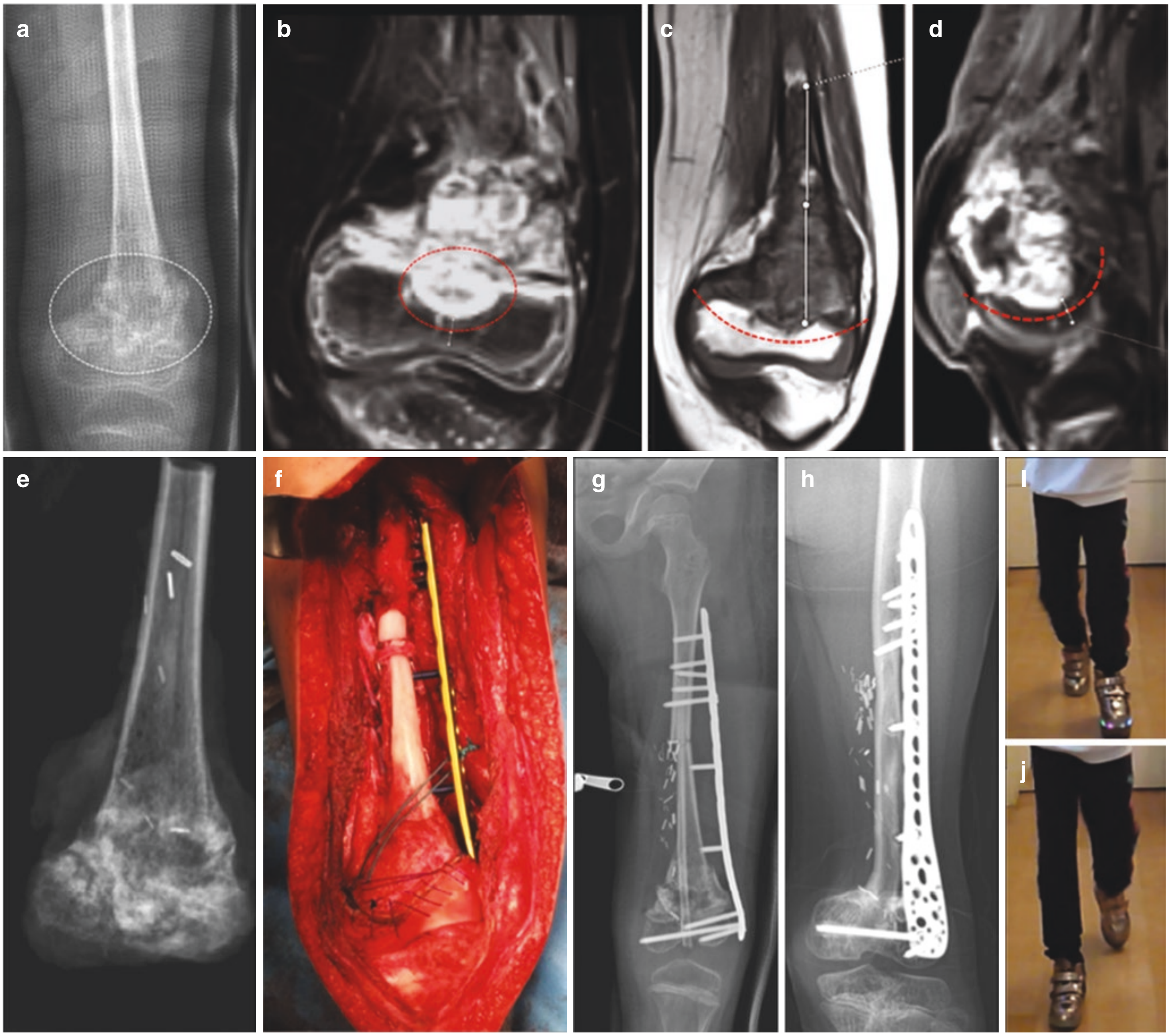


Fig. 1.15 Anteroposterior femur radiograph and coronal MRI section show pathological fracture and epiphyseal invasion in a 5-year-old non-metastatic female patient with distal femur osteosarcoma (**a**, **b**). The patient fell into a "gray-zone" category since she was not the ideal candidate for either intercalary biological reconstruction or tumor prosthesis reconstruction. While her interim radiological response to neoadjuvant chemotherapy was moderate, the pathological fracture and the epiphyseal involvement made a joint salvage procedure questionable in terms of oncological safety. Tumor prosthesis, on the other hand, would predispose such a small child to all possible manageable and/or non-manageable future complications of implant reconstruction regardless of whether a growing prosthesis was used. The options of amputation or Van Nes rotationplasty were discussed with the family; however, the family rejected both treatment options. Eventually, intercalary (intraepiphyseal) resection and biological reconstruction were performed following preoperative radiotherapy, which is unconventional for osteosarcoma as well as in a small child. The resection yielded a shelled-out distal femur articular segment composed of articular and epiphyseal cartilage with very little bone stock, which resembled an orange-peel and hence the procedure was coined as "orange-peel resection" (**c**, **d**). The radiograph in (**e**) shows the resected specimen, while the intraoperative image in (**f**) demonstrates the extreme nature of the reconstruction since the fixation of the distal fragment had to be augmented by sutures. Early postoperative radiograph (**g**) shows the "frozen hotdog" (liquid nitrogen recycled autograft shell & inlaid vascular fibula combination) reconstruction. Postoperative radiograph at 5 years (**h**) shows excellent healing of the hotdog segment, while the patient has good knee function and ambulation despite limb length discrepancy (**i**, **j**)

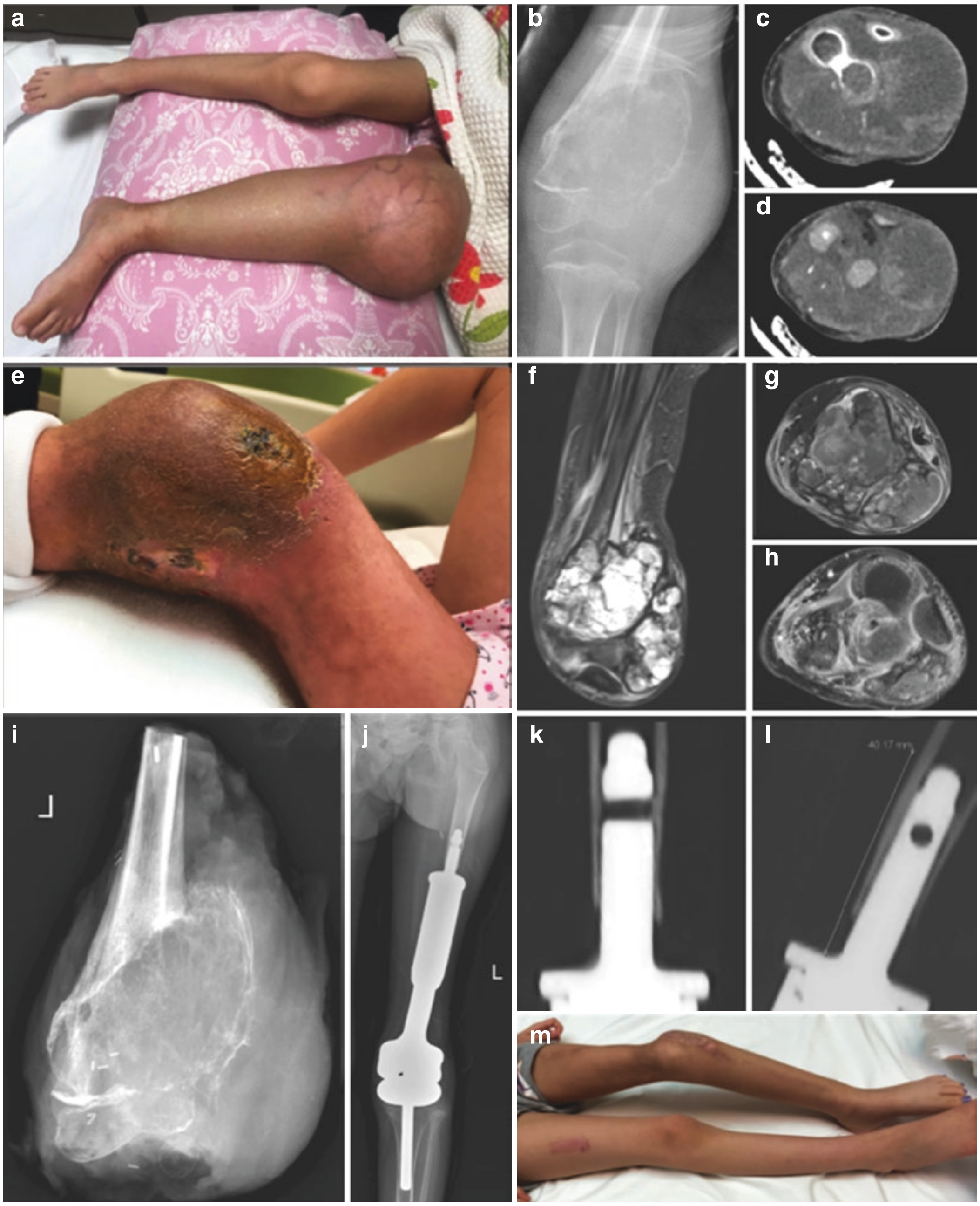


Fig. 1.16 Clinical image shows rapidly growing distal femur osteosarcoma causing a massive swelling and varicose veins around the knee of a 5-year-old-female patient at presentation (**a**). Plain radiograph shows pathological fracture of the distal femur (**b**), while axial CT images demonstrate that the distal femur epiphysis is engulfed by the tumoral mass (**c**, **d**). The patient had received two cycles of neoadjuvant chemotherapy with a two-drug regimen, under which the tumor had progressed, in another institution. The patient fell into a "gray-zone" category since she was not the ideal candidate for either intercalary biological reconstruction or tumor prosthesis reconstruction, similar to the case in Fig. 1.15. The options of amputation or Van Nes rotationplasty were discussed with the family; however, the family rejected both treatment options. A conventional osteosarcoma treatment approach did not seem compatible with safe limb salvage at this point. Therefore, a tailored multidisciplinary approach was required. After obtaining informed consent from the family regarding the risks of limb salvage surgery, both in terms of local and systemic tumor control, urgent concomitant chemoradiotherapy (ifosfamide and etoposide, 10 × 300 cGy) followed by one cycle of methotrexate was administered. Remarkable shrinkage of the tumor even with clinical examination 3 weeks after starting chemoradiotherapy was found to be encouraging for limb salvage (**e**). While MRIs at 4 weeks of oncological treatment showed decrease in tumor size with heterogeneous areas of tumor necrosis, extensive epiphyseal involvement eliminated any possibility of joint salvage and intercalary biological reconstruction (**f**–**h**). Planning of tumor prosthesis reconstruction posed yet another challenge. Even if the remaining proximal femoral segment could accommodate the femoral stem, there would be no bone stock left for future revisions or any lengthening procedure. Eventually limb salvage was performed with wide intraarticular resection and reconstruction with distal femur tumor prosthesis (**i**, **j**). A 4-cm-long custom-made pentagonal stem was used to spare proximal femur bone stock (**k**, **l**). Clinical image at postoperative 6 months shows successful limb salvage in this patient, who was still under oncological treatment without any evidence of disease at the time this work was being prepared for publication (**m**)

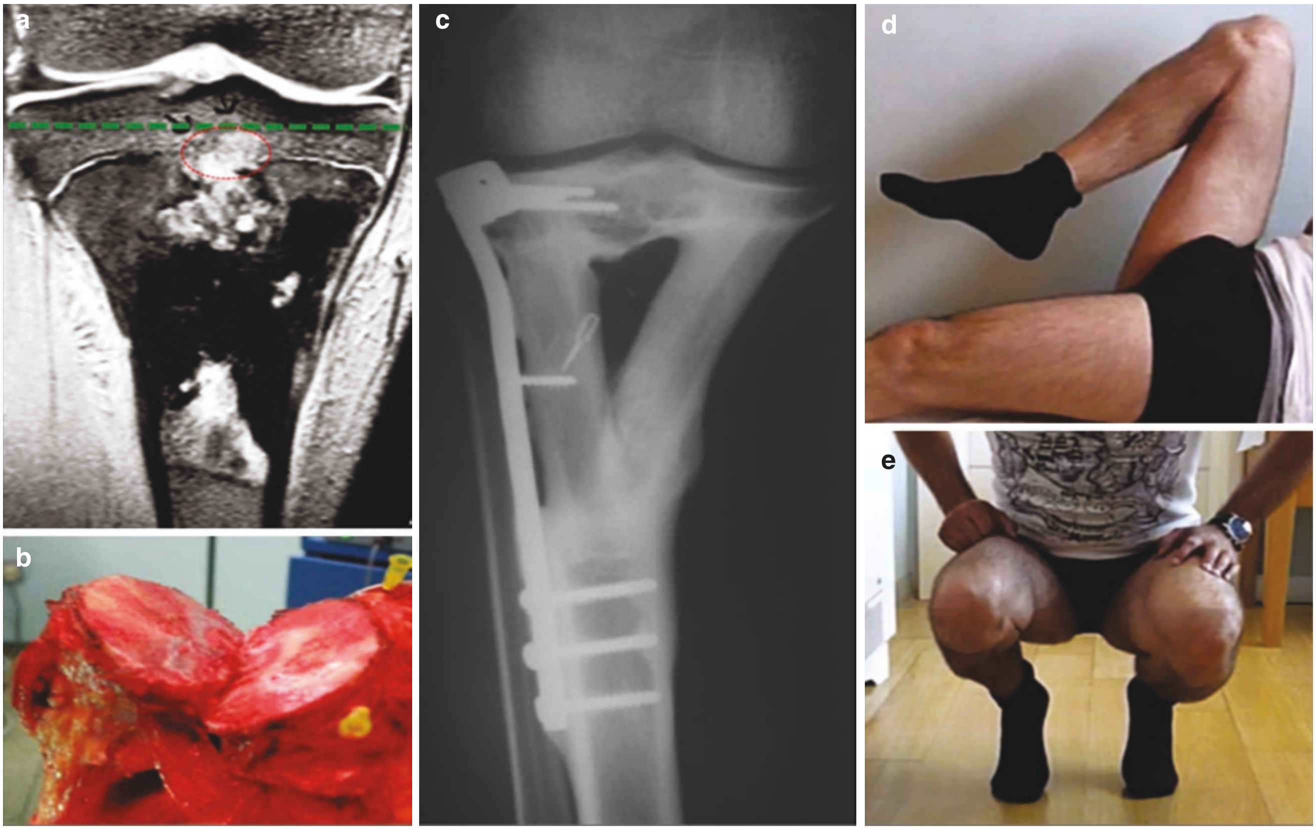
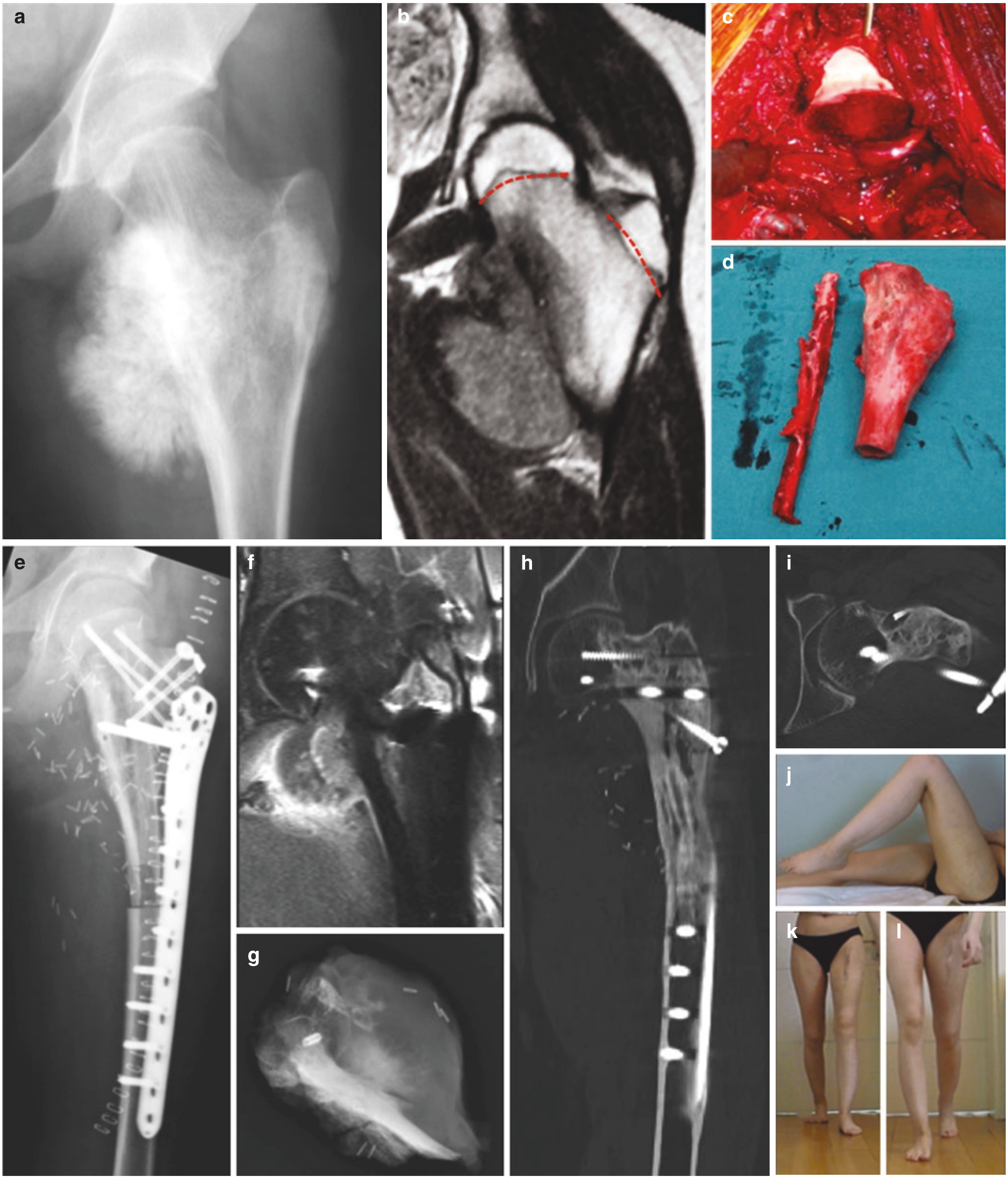


Fig. 1.17 Post-chemotherapy coronal MRI shows epiphyseal invasion in a 15-year-old non-metastatic male patient with proximal tibia osteosarcoma (**a**). The tumor did not have a significant soft tissue component or intramedullary extension. There was no sign of pathological fracture. While the epiphyseal involvement made an intercalary resection risky, all other prognostic factors favored a biological reconstruction. Following a discussion with the patient and the patient's family regarding the risks and benefits of a joint-preserving resection and obtaining informed consent, limb salvage was performed with biological reconstruction. An intraepiphyseal osteotomy was performed as planned in the coronal MRI section (green dashed line in **a**). Since the thickness of the remaining proximal tibia articular segment resembled a biscuit, the resection was coined as the "biscuit procedure" (**b**). Radiograph at postoperative 15 years shows excellent hypertrophy of the double-barrel vascular fibula reconstruction in the metaphyseal region with no degenerative changes in the knee joint (**c**). The patient has completely normal knee function (**d**, **e**)

Fig. 1.18 The plain radiograph (**a**) and the MRI (**b**) demonstrate parosteal osteosarcoma of the proximal femur in a 12-year-old-female patient. While the MRI gives the impression that only the medial cortex of the femoral neck and the lesser trochanteric region is involved, it must be remembered that parosteal osteosarcoma is neither chemo- nor radio-sensitive and therefore surgical treatment with wide resection is the absolute rule. Taking into consideration the young age of the patient and the potential detrimental effects of proximal femur tumor prosthesis on especially the acetabulum, an intercalary biological reconstruction was intended. The risks and benefits of such a reconstruction were discussed with the family. One of the two main challenges regarding an intercalary resection in this setting was preserving the blood supply and thus avoiding avascular necrosis of the femoral head. The other challenge was to avoid compromising the surgical margins. The planned proximal osteotomy sites in the subcapital region and at the trochanteric apophysis are marked with red dashed lines (**b**). First intraoperative image (**c**) shows the femoral head following intercalary resection (**c**). The articular cartilage and the bleeding cut surface of the femoral head can be clearly seen. The second intraoperative image (**d**) shows the free vascular fibula and the liquid-nitrogen recycled autograft before they were combined into a frozen hotdog graft. Early postoperative radiograph demonstrates biological reconstruction of the proximal femur with the "frozen hotdog" technique (**e**). A local recurrence developed in the inferior aspect of the femoral neck 4 years after the index operation and soon after the patient was allowed to bear full weight without assistive devices for the first time since the operation (**f**). Despite this discouraging complication, the locally recurring mass was resected by preserving the original reconstruction (**g**). The CT images obtained 9 years after the index operation and 5 years after the resection of local recurrence demonstrate full consolidation of the hotdog segment, with a completely preserved hip joint and no evidence of disease (**h**, **i**). She has good range-of-motion in her hip and is ambulatory without any pain or limp (**j**–**l**)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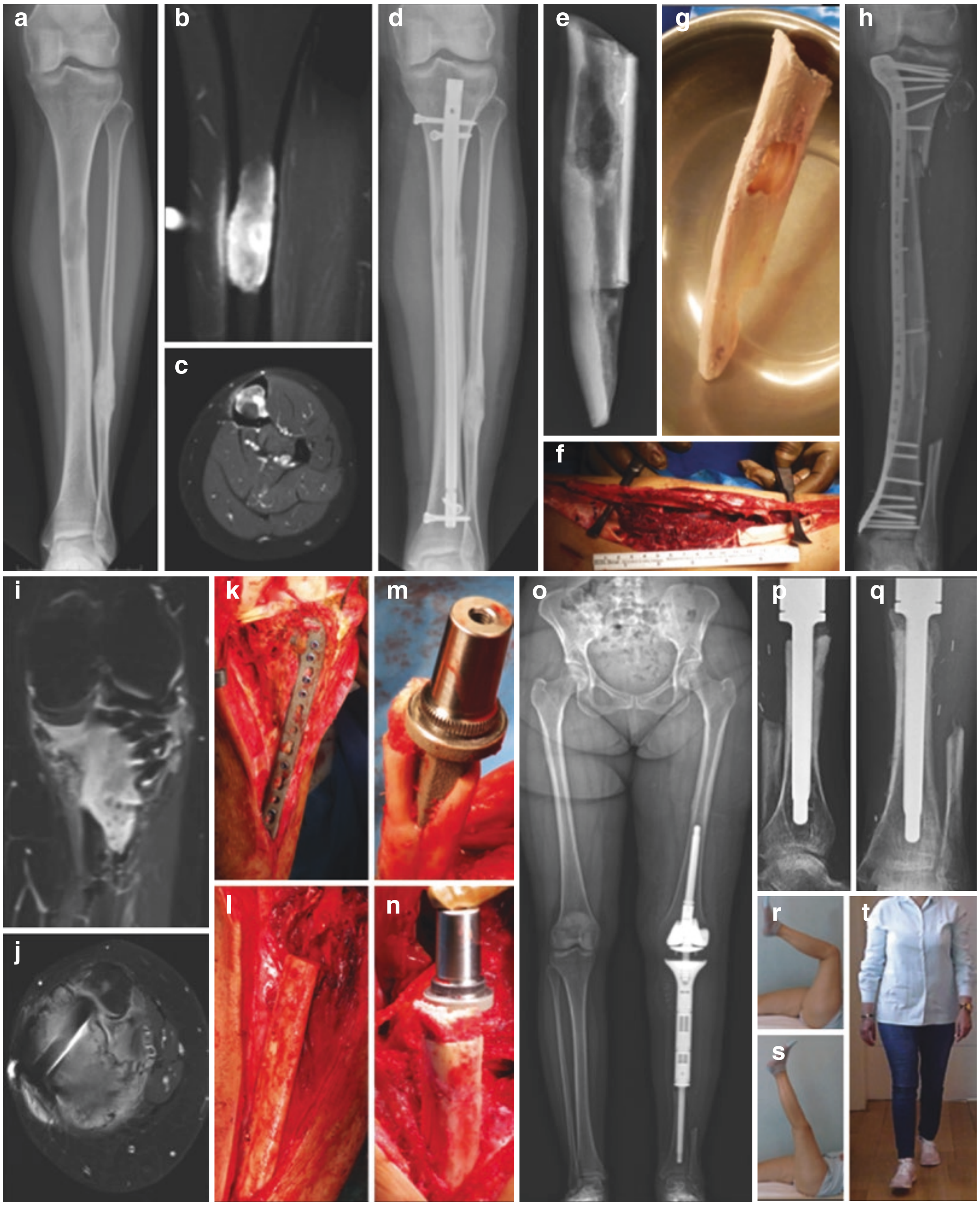

Fig. 1.19 The plain radiograph shows a lytic lesion in the proximal tibial diaphysis and a sclerotic lesion in the distal fibular diaphysis in a 46-year-old-female patient (**a**). Coronal and transverse MRI sections show the intramedullary tibial lesion with cortical thinning and imminent pathological fracture (**b**, **c**). An open biopsy (both for tibia and for fibula) and frozen pathological examination were performed to rule out any malignancy. The frozen exam yielded fibrous dysplasia in the tibia and non-specific non-malignant findings in the fibula. A prophylactic intramedullary (IM) nail fixation was performed in the same session (**d**). The definitive pathological examination of the whole biopsy specimen, however, yielded osteofibrous dysplasia (OFD) like adamantinoma, which required wide resection of all contaminated volume, with amputation rather than limb salvage emerging as a reasonable treatment option. From this point on, the patient fell into a "gray-zone" category both in terms of feasibility of a safe resection and difficulty of reconstruction. The challenging situation was explained to the patient, who opted for a limb salvage procedure, understanding the oncological risks associated with limb salvage regardless of reconstruction method. Following removal of the IM nail, tibial diaphyseal segment harboring the lytic lesion was resected as shown by the radiograph of the specimen (**e**). Previously biopsied distal fibular segment was also removed. Subsequently, a frozen hotdog reconstruction was performed using the liquid-nitrogen recycled tibial segment with transposition of the remaining ipsilateral fibula (**f**–**h**). Despite excellent healing of the biological reconstruction, local recurrence was observed in the proximal tibia as shown by coronal and transverse MRI sections at 20 months postoperatively (**i**, **j**). Once again, the patient was offered amputation as a potential treatment option. Conversion from biological to implant reconstruction was also proposed to the patient as a "gray-zone" indication in terms of both oncological outcome and possible anchorage problems. The mutual decision was to continue with limb salvage. Intraarticular wide resection of the proximal tibia was performed together with the locking plate (**k**). Significant length of distal tibial diaphysis, which had been previously reconstructed with frozen hotdog technique, could be spared for prosthesis stem insertion (**l**). Pentagonal stem was inserted into the distal tibia with excellent primary stability and the bone–prosthesis interface was augmented with a chunk of cancellous autograft obtained from preparation of the femoral side (**m**, **n**). The standing AP orthoroentgenogram shows the proximal tibia prosthesis in the early postoperative period (**o**). Radiographs (**p**, **q**) and clinical pictures (**r**–**t**) at 24 months postoperatively following implant reconstruction show excellent radiological and functional outcome. Furthermore, the patient remained tumor-free at the last follow-up visit

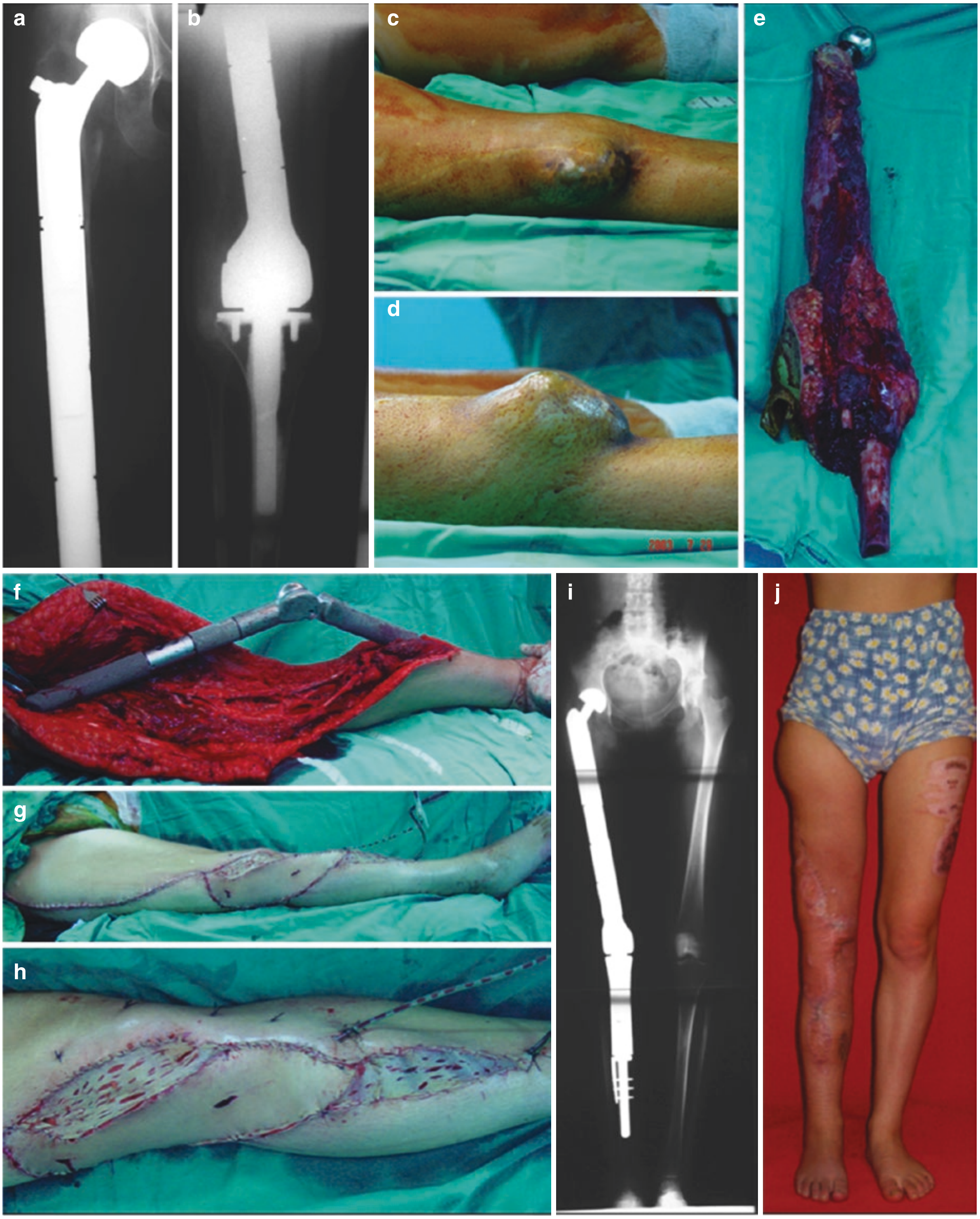

Fig. 1.20 A 16-year-old-female osteosarcoma patient presented with local recurrence in the anterior aspect of her knee, in the setting of a total femur prosthesis, which was implanted in another institution (**a**–**d**). The case was considered to fall into the "gray-zone" category in terms of decision-making and execution of treatment plan. Amputation was a valid treatment option from the oncological perspective. However, an amputative surgery would necessitate hip disarticulation, which would be devastating from the psychological perspective of the patient. The possibility of limb salvage, which could achieve wide margins comparable to that of an amputation, was sought. Classic tumor principles dictated the removal of all tissue volume contaminated by the previous procedure. An extreme musculoskeletal defect with extreme reconstructive challenges could be anticipated in such a resection. The mutual decision of the surgeon and the patient's family was to perform limb salvage, with the informed consent that limb salvage did not guarantee any systemic tumor control. The locally recurring tumor was widely resected, including the whole implant and the proximal half of the tibia (**e**). The massive osseo-articular defect was reconstructed with a total femur plus proximal tibia replacement prosthesis (**f**). The massive soft tissue defect, on the other hand, required advanced microsurgical reconstruction involving the transfer of a free chimeric serratus anterior—latissimus dorsi myocutaneous flap as well as extensive split-thickness skin grafting (**g**, **h**). Standing AP orthoroentgenogram at 6 months postoperatively shows stable implant with good alignment and negligible limb length discrepancy (**i**), while the clinical image at the same time demonstrates excellent wound healing (**j**)

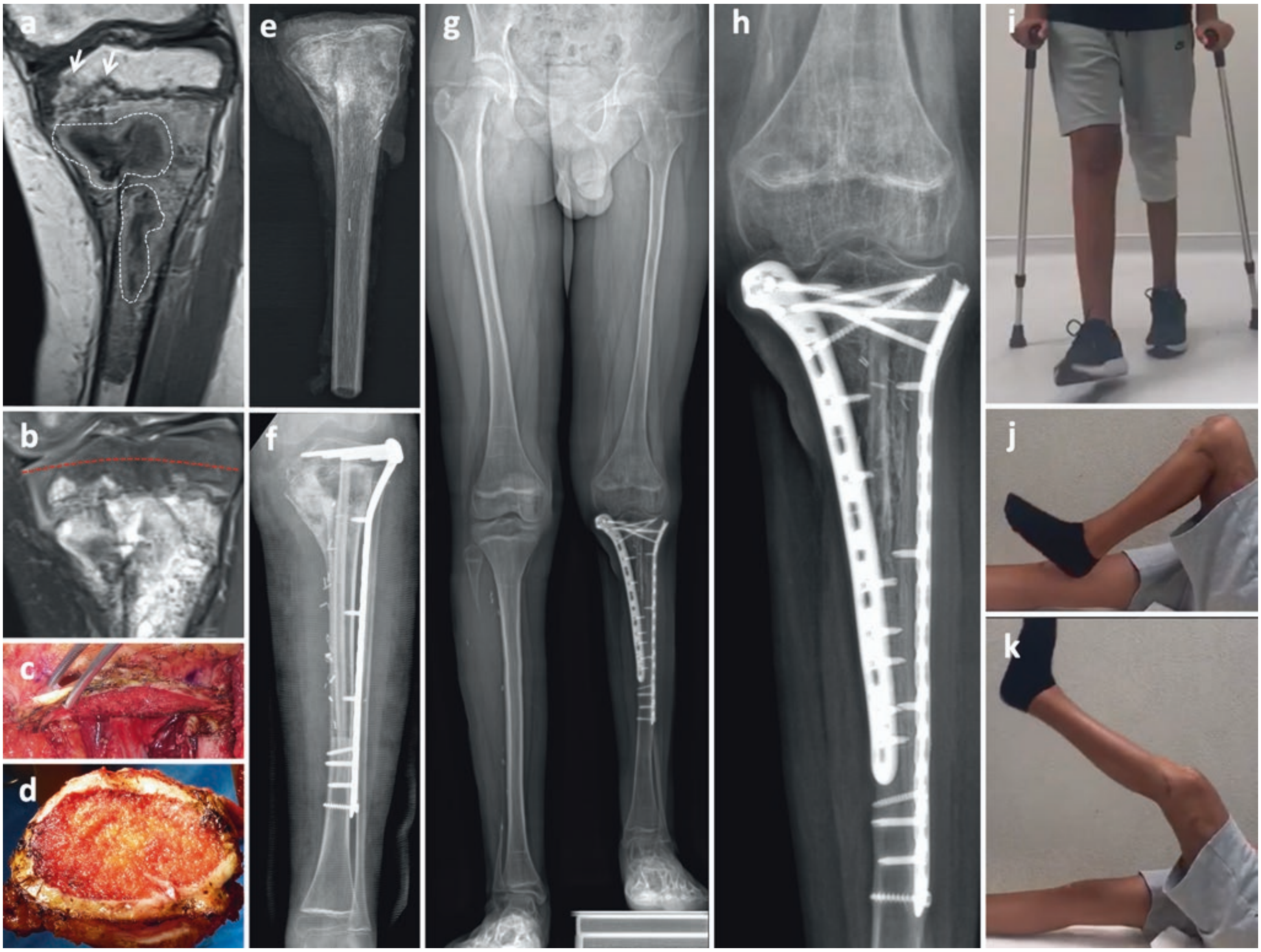

Fig. 1.21 Coronal section from post-neoadjuvant preoperative contrast-enhanced MRI shows osteosarcoma of the proximal tibia in a 9-year-old non-metastatic male patient (**a**). At presentation, the patient had a pathological fracture accompanied by significant soft tissue component and epiphyseal tumor extension. Despite the difficulty of achieving a safe intercalary resection in such a setting, biological reconstruction with joint salvage was aimed after discussing the risks and benefits of the treatment options with the family. To facilitate resectability of the tumor with safer margins, concomitant chemoradiotherapy (cisplatin, 10 × 300 cGy) was administered preoperatively in addition to the standard neoadjuvant chemotherapy regimen. Persistent epiphyseal involvement (white arrows) and areas of tumor necrosis (encircled by white dashed lines) can be observed (**a**). An intraepiphyseal osteotomy was planned just below the joint surface (red dashed line) in a similar fashion to the biscuit procedure described in Fig. 1.17 (**b**). The first intraoperative image shows the proximal tibia articular segment with only the cartilage remaining on the medial aspect after the resection (**c**). The second intraoperative image shows the resected segment from the superior aspect with macroscopically intact margins (**d**). The radiograph of the resected segment demonstrates successful execution of the planned osteotomy (**e**). Early postoperative radiograph shows "frozen hotdog" (liquid nitrogen recycled autograft shell & inlaid vascular fibula combination) reconstruction of the proximal tibia (**f**). The patient underwent augmentation of the medial tibial plateau with structural iliac autograft and medial proximal locking plate 16 months after the index procedure. At 5 years postoperatively, the patient has a limb length discrepancy of 65 mm (**g**). Follow-up radiograph at 5 years shows that the diaphyseal part has fully consolidated while there is some resorption in the metaphyseal part of the recycled bone and the medial tibial plateau is still defective, causing the proximal edge of the medial plate to articulate with the medial femoral condyle (**h**). The patient is allowed to bear weight as tolerated with a pair of crutches (**i**) and the knee range-of-motion is good (**j**, **k**). Although the radiological and functional outcomes are not excellent, oncological objectives have been achieved so far. The ipsilateral distal femoral epiphysis has been spared and the knee function has been remarkably preserved. The reconstruction can be revised using another biological tool such as massive allograft or could be converted to tumor prosthesis if everything else fails

sion to another limb salvage method (Fig. 1.21) or to a more functional amputation at a later age, for example, for a skeletally immature child.

1.5 Conclusion

Both biological and non-biological methods have their own advantages and disadvantages. At the same time, each method has its unique indications as well as overlapping ones. While the choice of treatment is clear-cut for some cases, the indications might fall into a "gray zone" category in others where multiple parameters must be considered simultaneously in the light of surgeon's and/or institution's capabilities and experience. To conclude which reconstruction should be preferred when and why, one must first remind the unchanging limb salvage philosophy with the following analogy:

> Tumor resection with safe margins denotes "1"; each achieved limb salvage goal puts a "0" beside "1", adding value to the treatment. Thus, preserving the limb yields "10", a functional limb "100", good cosmetic appearance "1000" and so on. If the margins are compromised, however, the surgeon and the patient are left with a "0" to begin with and all reconstruction efforts whether biological or implant are cancelled out.

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