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SURGICAL TECHNIQUE

Hemiarthroplasty of Pedicle-Frozen Proximal Tibia for Primary Malignant Bone Tumours

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Abstract

The proximal tibia is one of the most common locations for primary malignant bone tumours and is usually seen in a population that has not attained skeletal maturity. Most of the surgical techniques for resection and reconstruction of the proximal tibia in children involves sacrificing the distal femoral epiphysis, which leads to a significant limb length discrepancy. Hemiarthroplasty is a relatively lesser known technique for knee joint reconstruction that preserves one of the epiphyses around the knee joint. Pedicle freezing is a sterilization technique used to treat malignant bone tumours, without performing an osteotomy of the diaphysis, thereby preventing non-union which is the most common complication of biological reconstruction techniques. We describe the surgical technique of hemiarthroplasty of the pedicle-frozen proximal tibia for malignant bone tumours of the proximal tibia. This is a novel, safe and effective reconstructive method in children, resulting in reduced limb length discrepancy and excellent functional outcomes.

Keywords Limb salvage · Pedicle freezing · Hemiarthroplasty of knee · Osteosarcoma · Bone tumour

Introduction

After the distal femur, proximal tibia is the second most common site of involvement for primary malignant bone tumours, and the majority of these bone tumours occur in the paediatric and adolescent age group with significant remaining growth potential [1]. Biological reconstruction of the proximal tibia following resection of bone tumour in the form of allografts or recycled autografts are expected to provide long-lasting reconstruction [2]. Most of the surgical techniques for resection and reconstruction of the proximal tibia in children involves sacrificing the distal femoral epiphysis, which leads to a significant limb length discrepancy. In young patients with proximal tibia tumours not extending into the knee ligaments and the capsule, resurfacing or hemiarthroplasty of the proximal tibia spares the physis of the distal femur, thereby reducing the final limb length discrepancy at skeletal maturity [3]. Among the limited reported cases of hemiarthroplasty around the knee, the joint resurfacing has all been performed on bone allograft, and the resurfaced allograft has been used to reconstruct the resected proximal tibia [3–6]. There is no literature available for hemiarthroplasty performed on sterilized bone autograft following resection for malignant bone tumours of the extremities.

We report a novel surgical technique of hemiarthroplasty in a pedicle-frozen proximal tibia that has been sterilized with liquid nitrogen to eradicate the tumour cells, without performing the osteotomy to deliver the tumour-bearing segment from the limb.

Case selection is more important than the surgical technique itself and this technique is beneficial in paediatric

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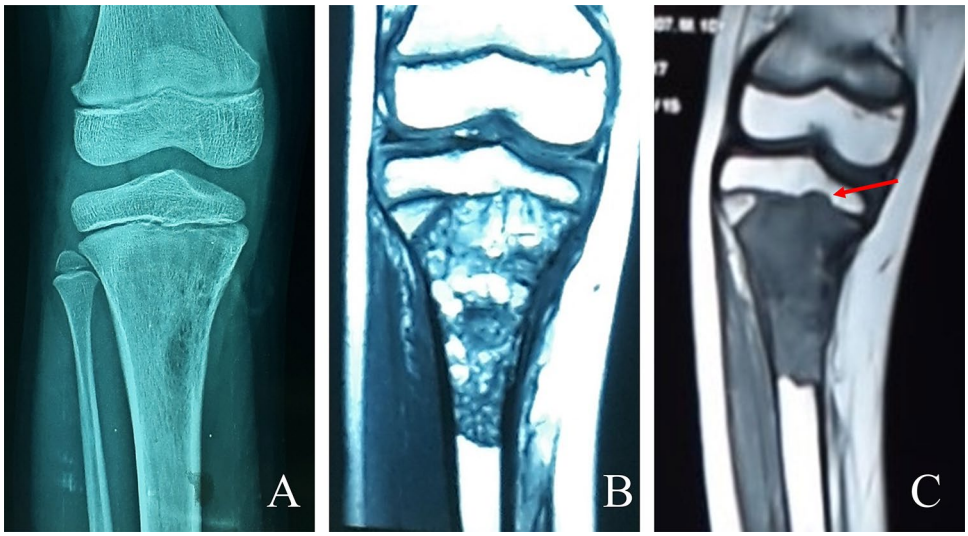

Fig. 1 Plain radiograph of the right knee with an osteolytic lesion in the medial aspect of the proximal tibia metaphysis with a wide zone of transition, in a patient with high-grade conventional osteosarcoma (**A**). T2-weighted magnetic resonance imaging of the proximal tibia before chemotherapy with tumour extending till the growth plate and no obvious extension into the epiphysis (**B**). T1-weighted magnetic resonance imaging after two cycles of chemotherapy with varus collapse of the proximal tibia and suspicious breach of the growth plate (arrow) and tumour extension into the epiphysis (**C**)

Fig. 2 Planned line of incision over medial aspect of right knee and leg including the biopsy scar, with patient in supine position

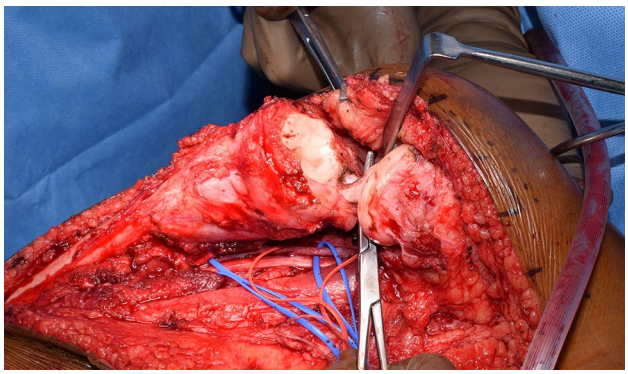

Fig. 3 Subluxated knee joint with posterior cruciate ligament and tagged posterior tibial neurovascular bundle

patients in whom further significant growth is expected from the distal femoral physis. The tumour has to the localized to the proximal tibia with no skip lesions and articular or capsular extension. Non-metastatic disease with limited soft tissue extension and good response to neo-adjuvant chemotherapy are favourable indications for this technique. In metaphyseal paediatric malignant bone tumours of the long bones, if the epiphysis is spared by the tumour, transepiphyseal resection is attempted to salvage the knee joint. But if the physeal growth plate is breached with tumour extension into the epiphysis, joint cannot be salvaged and has to be reconstructed (Fig. 1).

Surgical Technique (Video 1)

With the patient in a supine position and under general anaesthesia and tourniquet in the thigh, a curvilinear incision should be made along the medial aspect of the distal thigh and knee joint extending over the anteromedial aspect of the right proximal leg (Fig. 2). Gracilis and semitendinosus tendons (medial hamstrings) should be identified on subcutaneous dissection over the medial aspect of the proximal leg and tagged with fibre wires to prevent them from being retracted proximally into the thigh. With the knee joint in flexion, the medial gastrocnemius should be cut at its attachment to the posterior femoral condyle taking care not to damage its vascular pedicle and the underlying posterior tibial neurovascular bundle is isolated and tagged. The patellar tendon, knee joint capsule and medial collateral ligament should be cut close to their respective attachment on the tibia. The cruciate ligaments exposed after anterior subluxation of the knee joint is cut close to the tibial articular surface (Fig. 3). While maintaining adequate soft tissue margins circumferentially, the proximal half of the tibia is skeletonized and separated from the surrounding tissue and prepared for pedicled freezing (Fig. 4).

The pedicled freezing sterilization of the proximal tibia is performed as per the described standard technique [7] (Fig. 5). The intramedullary extent of the tumour on

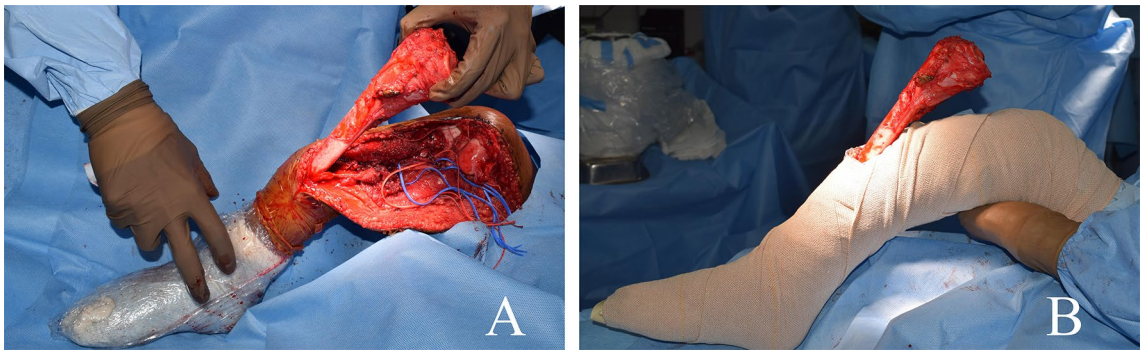

Fig. 4 Skeletonized proximal tibia before (**A**) and after (**B**) preparing for pedicle freezing liquid nitrogen sterilization

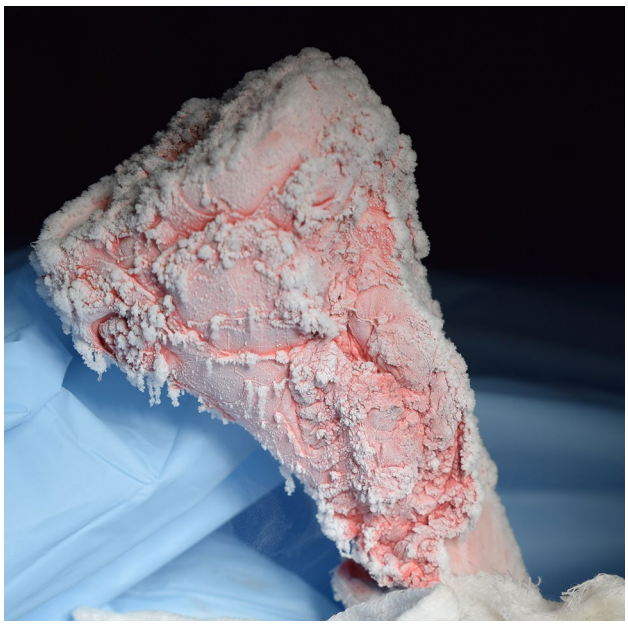

Fig. 5 Frozen proximal tibia being thawed in room air

Fig. 6 Implantation of frozen proximal tibia with bone cement around the proximal tibial base plate and an uncemented stem (small-sized cemented tibial tray [Nexgen LPS, Zimmer, Warsaw, IN, USA])

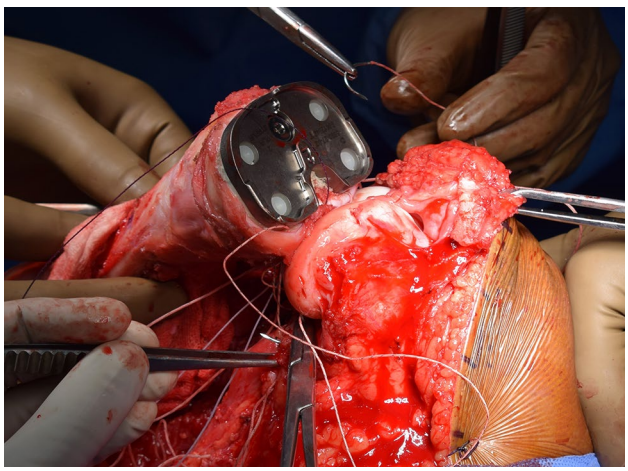

Fig. 7 Reconstruction of posterior capsule with multiple non-absorbable fibre wires

radiological examination along with an additional 2 cm as oncological margin is marked and the proximal tibia is immersed in liquid nitrogen upto the marked extent. Following cryo-sterilization and thawing, the medullary canal of the proximal tibia is reamed, and a seven-degree posterior slope tibial cut is taken with the help of a cutting jig. The articular surface of the tibia is reconstructed using a commercially available tibial tray of a total knee arthroplasty system, with bone cement (Fig. 6). Stem extension (preferably uncemented) is used with the tibial tray to obtain anchorage into the healthy bone (shaft of tibia not included in cryo-sterilization), such that the stem extends for at least 4 cm distal to the junction of the frozen–unfrozen bone interface.

Once the cement is set, a suture anchor with multiple fibre wires is inserted into the attachment site of the posterior cruciate ligament (PCL) on the recycled tibia. The knee joint is relocated and the posterior capsule of the knee joint is first reconstructed with adequate tension, followed by the PCL (Fig. 7). A polyethene tibial insert that articulates well

with the distal femoral articular surface is chosen and the insert which is thick enough to keep the knee joint taut is implanted. The capsule of the knee joint is then circumferentially reconstructed with multiple interrupted non-absorbable sutures and fibre wires. The patellar tendon and the medial hamstrings are anchored back into their respective site of attachments and the proximal tibia is covered by rotating the medial gastrocnemius flap [8] (Fig. 8). The wound is closed in layers over a suction drain. The knee joint is immobilized with a long posterior knee slab till the wound heals and is later immobilized on a long cylindrical cast for the next 2 months.

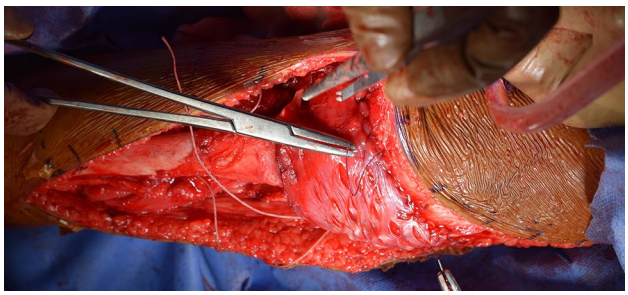

Fig. 8 Pedicled medial gastrocnemius muscle flap rotated over the sterilized bone forming a pseudocapsule

Upon removal of the cast, gentle assisted knee range of motion is initiated. Partial weight-bearing is started about 3 months after surgery and weight-bearing is gradually increased over the next 3 months. An adjustable walker should be used for support while ambulating for the first 6 months and later replaced with an elbow crutch for the next 3 months. Full weight-bearing ambulation without support is generally started around 7–9 months after surgery. Care is taken with weight-bearing and assistance is compulsory in patients receiving adjuvant chemotherapy to prevent fracture. Serial plain orthogonal radiographs should be obtained once every 3 months for the first year, and once in 6 months thereafter. Retained growth at the distal femoral growth plate as evidence in the radiograph depicts successful intent of the procedure (Fig. 9). Recycled proximal tibia gradually gets hypertrophied (Fig. 9).

Discussion

While reconstructing the proximal tibia following bone tumour resection, maintaining the mechanical stability at the knee joint, allowing biological reconstruction of the extensor mechanism, and retaining maximum bone stock, all are crucial. The technique of bone allograft-prosthesis composite (APC) combines the advantages of prosthetic and

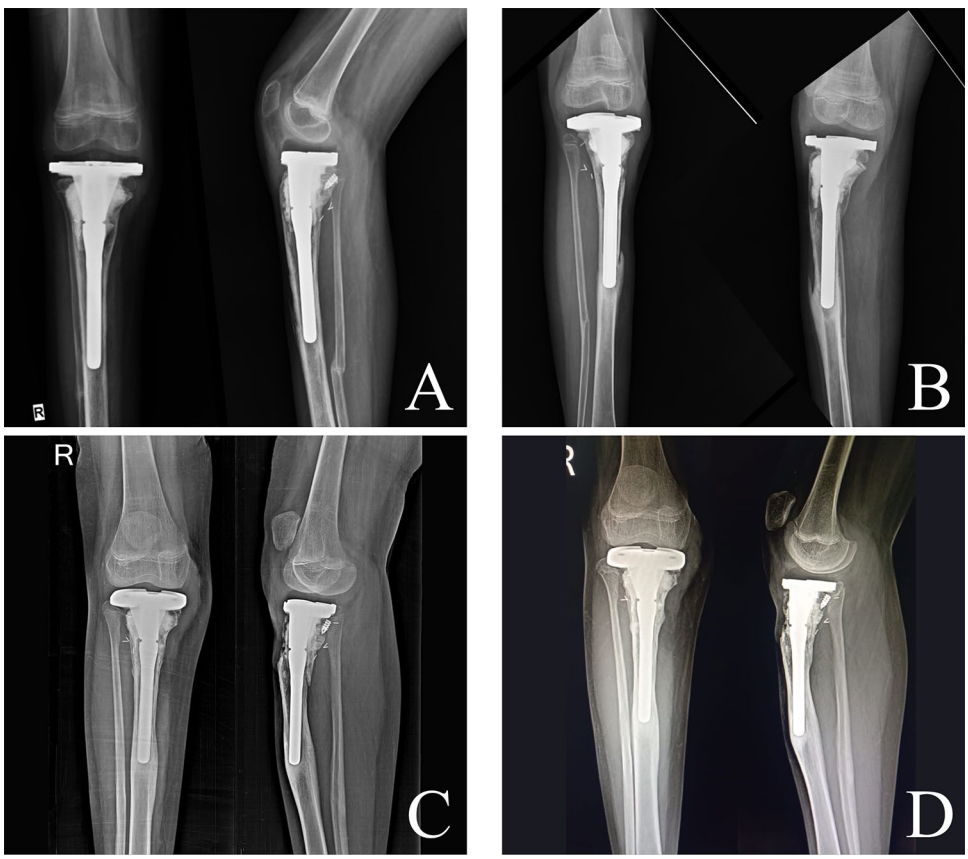

Fig. 9 Plain radiograph of the proximal tibia and knee with anteroposterior and lateral views following pedicle freezing and hemiarthroplasty of the proximal tibia 1 year (**A**), 2 years (**B**), 3 years (**C**) and 4 years (**D**) after the surgery

biological reconstruction, providing satisfactory functional outcomes and survival of the construct [9]. However, APC reconstruction of the proximal tibia in children necessitates resection of distal femoral physis, which can result in limb length discrepancy (LLD) at skeletal maturity. To reduce the LLD, only the proximal tibia can be resurfaced (hemiarthroplasty) and made to articulate with the distal femur, without removal of the distal femoral physis. Hemiarthroplasty can be performed as a definitive procedure or used as a temporary measure to extract the full potential of the distal femoral growth plate, before performing definitive surgery at adolescence or adulthood. The surgical technique of hemiarthroplasty of the proximal tibia has been elaborately described [3]; but, there are very few studies available in the literature reporting the outcome of this technique [4, 5]. Campanacci et al. reported good or excellent functional outcomes at a mean follow-up of 85 months in 8 of their 13 paediatric patients, who underwent hemiarthroplasty of the allograft for proximal tibia reconstruction. The mean construct survival was 68 months; five patients in whom implant was retained for more than 100 months showed radiographic evidence of degenerative changes in the distal femur, but only one patient presented with severe arthritis [4].

Osteoarticular allograft of the proximal tibia is another method of saving the distal femur growth potential. Despite having the biological advantage over an endoprosthesis, osteoarticular allografts are associated with high mechanical failure rates and infection [10, 11]. There is a high risk of subchondral collapse if osteoarticular allografts as creeping substitution do not occur at the articular end [11]. The subchondral collapse may be the reason why osteoarticular allografts fail more frequently than intercalary allografts, and prosthetic replacement of the articular surface may prolong the survival of osteoarticular allografts [12].

Endoprosthesis (EP) reconstruction of proximal tibia results in early return to activities, independent ambulation and weight-bearing. The loss of distal femoral growth plate adds to the LLD and the rates of complications tend to increase with age; hence EP does not seem to be a favourable option in younger individuals [13]. Even non-invasive lengthening implants have not shown benefits over conventional designs and are associated with a higher risk for infection and amputation [14].

Tsuchiya et al. described the technique of sterilizing tumour-bearing bone with the hypothermic effect of liquid nitrogen and reimplantation of the recycled autograft [15]. In contrast to other sterilization techniques such as autoclaving, pasteurization and irradiation, the capacity of bone induction due to retention of bone morphogenic proteins is maintained during cryo-sterilization thereby facilitating bone union and strength. The technique of cryo-sterilization was later modified to prevent the complications of delayed union and nonunion [16]. In the modified "pedicle freezing" technique, the diaphyseal osteotomy is avoided, and the tumour-bearing segment is delivered extracorporeal from the surrounding soft tissue attachments for sterilization while maintaining the bony continuity [7, 16]. Following pedicle freezing of the proximal tibia, either recycled bone-prosthetic composite or an osteoarticular reconstruction is performed to obtain a functional knee joint. The technique described here involves a combination of preserving the growth plate of the distal femur by performing the hemiarthroplasty of the proximal tibia and the advantage of not performing a tibial osteotomy by performing pedicle freezing. As per the combined knowledge of the authors, hemiarthroplasty of a pedicle-frozen proximal tibia has never been reported to date.

Deep infection and failure of the extensor mechanism are the common early complications of biological reconstruction of the proximal tibia [4]. A longer follow-up is warranted as late complications of bone allograft or recycled autograft like metaphyseal collapse or fracture and bone resorption are not uncommon [4, 17]. There is a high prevalence of metaphyseal fracture (up to 80%) in osteoarticular proximal tibia reconstructions [18]. Manfrini et al. [3] in their initial description of hemiarthroplasty of the proximal tibia, used a short-stemmed tibial component and a plate that spanned adequately beyond the allograft into the host bone to stabilize the construct. Eventually, with the experience of the technique, they suggested the use of a long-stemmed tibial component to reduce the chances of graft fracture; they also recommended against the use of bone cement in the host bone as it sacrifices the diaphyseal bone stock in children [3]. We prefer to use bone cement around the metaphysis of the frozen bone and underneath the tibial baseplate, with an uncemented stem extension that extends well into the unfrozen host bone. The pedicle-freezing technique enables not to supplement the construct with plate fixation as osteotomy is not performed. Lesser orthopaedic hardware and limited use of bone cement can be considered advantages, especially in a younger age group of patients who might require additional surgeries in the future where the preserved bone stock may be essential.

Conclusion

Indications for hemiarthroplasty is crucial; children who are younger than 12 years at the time of surgery, with tumour not involving the articular cartilage, knee joint capsule or the cruciate ligaments are ideal candidates for the procedure [3]. Hemiarthroplasty around the knee joint in children considerably lessens the LLD at skeletal maturity, reducing the number of surgeries and allowing surgeons more options for reconstruction [5]. Liquid nitrogen sterilization of bone tumours yield recycled autografts with better bone healing with fewer complications [17]; pedicle freezing of

the proximal tibia avoids the need for an osteotomy its associated complications. Hemiarthroplasty of a pedicle-frozen proximal tibia in a child is a novel, simple and effective technique of biological reconstruction in select cases.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Ethical Standard Statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed Consent Informed consent was obtained from participants included in the study.

References

1. Ottaviani, G., & Jaffe, N. (2009). The epidemiology of osteosarcoma. *Cancer Treatment and Research, 152*, 3–13.
2. Innocenti, M., Abed, Y. Y., Beltrami, G., Delcroix, L., Manfrini, M., & Capanna, R. (2009). Biological reconstruction after resection of bone tumors of the proximal tibia using allograft shell and intramedullary free vascularized fibular graft: Long-term results. *Microsurgery, 29*(5), 361–372.
3. Manfrini, M., Donati, D., Colangeli, M., & Campanacci, L. (2016). Resurfaced allograft-prosthetic composite for proximal tibial reconstruction in children. *JBJS Essential Surgical Techniques, 6*(1), e4.
4. Campanacci, L., Alì, N., Casanova, J. M., Kreshak, J., & Manfrini, M. (2015). Resurfaced allograft-prosthetic composite for proximal tibial reconstruction in children: Intermediate-term results of an original technique. *The Journal of Bone and Joint Surgery American Volume, 97*(3), 241–250.
5. Chung, S. H., Jeon, D. G., Cho, W. H., Song, W. S., Kong, C. B., Cho, S. H., et al. (2015). Temporary hemiarthroplasty with a synthetic device in children with osteosarcoma around the knee as a bridging procedure until skeletal maturity. *Journal of Surgical Oncology, 112*(1), 107–114.
6. Errani, C., Tanzi, P., Ferra, L., Campanacci, L., Donati, D. M., & Manfrini, M. (2021). Resurfaced allograft-prosthetic composite for distal femur reconstruction in children with bone tumor. *European Journal of Orthopaedic Surgery & Traumatology: Orthopedie Traumatologie, 31*(8), 1577–1582.
7. Hindiskere, S., Doddarangappa, S., & Chinder, P. S. (2020). What are the challenges and complications of sterilizing autografts with liquid nitrogen for malignant bone tumors? A preliminary report. *Clinical Orthopaedics and Related Research, 478*(11), 2505–2519.
8. Jentzsch, T., Erschbamer, M., Seeli, F., & Fuchs, B. (2013). Extensor function after medial gastrocnemius flap reconstruction of the proximal tibia. *Clinical Orthopaedics and Related Research, 471*(7), 2333–2339.
9. Donati, D., Colangeli, M., Colangeli, S., Di Bella, C., & Mercuri, M. (2008). Allograft-prosthetic composite in the proximal tibia after bone tumor resection. *Clinical Orthopaedics & Related Research, 466*(2), 459–465.
10. Jamshidi, K., Bahrabadi, M., & Mirzaei, A. (2017). Long-term results of osteoarticular allograft reconstruction in children with distal femoral bone tumors. *The Archives of Bone and Joint Surgery, 5*(5), 296–301.
11. Bus, M. P. A., van de Sande, M. A. J., Taminiau, A. H. M., & Dijkstra, P. D. S. (2017). Is there still a role for osteoarticular allograft reconstruction in musculoskeletal tumour surgery? *The Bone & Joint Journal, 99-B*(4), 522–530.
12. Ortiz-Cruz, E., Gebhardt, M. C., Jennings, L. C., Springfield, D. S., & Mankin, H. J. (1997). The results of transplantation of intercalary allografts after resection of tumors. A long-term follow-up study. *The Journal of Bone and Joint Surgery American Volume, 79*(1), 97–106.
13. Grimer, R., Belthur, M., Carter, S., Tillman, R., & Cool, P. (2000). Extendible replacements of the proximal tibia for bone tumours. *The Journal of Bone and Joint Surgery British Volume, 82*, 255–260.
14. Tsagozis, P., Parry, M., & Grimer, R. (2018). High complication rate after extendible endoprosthetic replacement of the proximal tibia: A retrospective study of 42 consecutive children. *Acta Orthopaedica, 89*(6), 678–682.
15. Tsuchiya, H., Wan, S. L., Sakayama, K., Yamamoto, N., Nishida, H., & Tomita, K. (2005). Reconstruction using an autograft containing tumour treated by liquid nitrogen. *The Journal of Bone and Joint Surgery British Volume, 87-B*(2), 218–225.
16. Tsuchiya, H., Nishida, H., Srisawat, P., Shirai, T., Hayashi, K., Takeuchi, A., et al. (2010). Pedicle frozen autograft reconstruction in malignant bone tumors. *Journal of Orthopaedic Science: Official Journal of the Japanese Orthopaedic Association, 15*(3), 340–349.
17. Araki, Y., Yamamoto, N., Hayashi, K., Takeuchi, A., Miwa, S., Igarashi, K., et al. (2021). Clinical outcomes of frozen autograft reconstruction for the treatment of primary bone sarcoma in adolescents and young adults. *Scientific Reports*. https://doi.org/10.1038/s41598-021-96162-5
18. Campanacci, L., Manfrini, M., Colangeli, M., Alí, N., & Mercuri, M. (2010). Long-term results in children with massive bone osteoarticular allografts of the knee for high-grade osteosarcoma. *Journal of Pediatric Orthopedics, 30*(8), 919–927.