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MUTARS® Humero pro Femur replacement: A novel reconstructive procedure after malignant bone tumor resection of the femur in young children

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ABSTRACT

Limb-preserving surgery in young children suffering malignant bone tumor of the femur is challenging due to the specific anatomical conditions. Extendable tumor endoprostheses are often oversized, while custom-made endoprostheses do not provide the intraoperatively required variability regarding reconstruction length. Allo- and autograft replacements, on the other hand, show high complication and revision rates. We report a novel reconstructive procedure after resection of malignant bone tumors of the femur in young children, and present our preliminary results of this technique.

1. Introduction

The occurrence of primary bone sarcomas of the femur is rare in children under the age of eight years. In these patients, the specific anatomical conditions represent a challenge to limb-salving treatment. Moreover, leg length discrepancies (LLD) have to be anticipated if the femoral growth plates cannot be preserved during tumor resection [1,2]. In recent decades, reconstruction with modular tumor endoprostheses has been established as the most commonly used treatment approach [3]. Expandable tumor prostheses offer the possibility of successive limb length equalization in children and have shown satisfactory functional results [4]. However, the implantation of conventional modular as well as growing tumor prostheses requires adequate bone proportions and sufficient soft tissue coverage, and may hence not be applicable in very young children [5]. Custom-made prostheses can address these particular anatomical challenges but impede intraoperative variability of the preplanned resection length. Auto- and allograft reconstruction, on the other hand, are linked with high complication and revision rates [6]. Moreover, availability is limited. Ablative procedures as well as rotationplasty provide reliable results regarding resection margins and functional outcome, but are cosmetically unfavorable and entail lifelong dependence on exoprostheses. Thus, there is still need for alternative treatment approaches for limb-sparing surgery in young children in whom the aforementioned procedures are not applicable or desirable.

In this article, we present a novel reconstructive technique which serves as a limb preserving, bridging procedure in young children suffering primary malignant bone tumor and evaluate the preliminary outcome.

2. Methods and surgical technique

A retrospective single center analysis of children under the age of eight years who were treated for malignant bone tumor of the femur (Ewing's sarcoma (n = 3) and osteosarcoma (n = 2)) between 2012 and 2020 was undertaken. A query of the hospital's electronic database was conducted to identify all patients who underwent either intraarticular distal femur resection (n = 3) or total femur resection (n = 2) and subsequent femoral reconstruction with modular components of the MUTARS™ system (Implantcast, Buxtehude, Germany). Pre- and postoperatively, all patients underwent chemotherapy according to the prevailing international trial protocols (EURAMOS and EWING 2008 respectively). Pre-operative local radiotherapy was not performed in any patient.

In total, 5 patients (2 female, 3 male) were identified and included in this study. Patient data are shown in Table 1.

All radiographic planning and measurements were conducted on

Abbreviations: a.p., anteroposterior; LLD, leg length discrepancy; MSTS, Musculoskeletal Tumor Society.

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calibrated radiographs with the PACS® system (GE Healthcare, Chicago, IL, USA) and the post processing software TraumaCad® (Brainlab, Munich, Germany).

The study was approved by our institutional review board (registration number: 2020–898-f-S) and was conducted according to the principles of the World Medical Association Declaration of Helsinki, 1964.

3. Surgical technique

After wide tumor resection including either the distal or the total femur with preservation of the extensor apparatus including the patella, reconstruction of the knee joint is performed by implantation of a MUTARS® (Implantcast, Buxtehude, Germany) distal humerus replacement. The humerus component is implanted with 180° rotation, in this way serving as a hinged joint replacement and allowing flexion of the knee joint of up to 100°. Diaphyseal reconstruction is performed with standard modular humeral components of the MUTARS® system. Implantation of a custom-made tibial plateau with a polished stem minimizes damage to the proximal tibial physis. In case of total femur reconstruction, application of a Trevira attachment tube allows refixation of the pelvitrochanteric muscles.

4. Case illustrations

4.1. Case # 1

A female patient presenting Ewing's sarcoma of the right femur received total femur resection and MUTARS® Humero pro Femur reconstruction at the age of 3 years. After immobilization of 2 weeks, the patient was allowed to start weight-bearing; flexion of the hip and knee joint was initially limited to 60°. Full range of motion was allowed after 3 months. Revision surgeries for lengthening of 10 mm each were performed 3, 3.5, 4, and 6 years after initial surgery, respectively. A triple pelvic osteotomy was performed at the age of 8 years to avoid dislocation of the hip joint due to dysplasia. 6 years after the initial surgery a periprosthetic joint infection occurred, which was handled by exchange of the modular components and by antibiotic treatment.

At the time of last follow-up at the age of 12 years, 9 years after tumor resection, the patient showed a remaining LLD of 13.5 cm (Fig. 1), 90° flexion of the hip and 60° flexion of the knee. The Musculoskeletal Tumor Society (MSTS) score was 21 points at the time of last follow-up [7]. The patient was provided with shoe lifts for LLD equalization, but was able to ambulate independently, without need for walking aids. There were no signs of local tumor recurrence. A revision surgery with exchange to an extendable tumor prosthesis is scheduled.

4.2. Case # 2

A female patient with osteosarcoma of the left distal femur received tumor resection and reconstruction of the distal and diaphyseal femur at the age of 8 years. Mobilization with full weight-bearing and free range of motion was initiated at the fourth day postoperatively. Revision surgery with exchange of the femoral stem was performed 3 years after tumor resection due to stem loosening.

At the time of last follow-up, 3 years after the initial surgery, the patient showed a remaining LLD of 3 cm (Fig. 2) and 90° flexion of the knee joint and was able to ambulate independently. The MSTS score was 24 points at the time of last follow-up.

4.3. Case # 3

A male patient aged 4 years presented with high-grade osteosarcoma and pathological fracture of the right distal femur. Due to the advanced stage of disease and metastatic pulmonary dissemination, treatment intentions were palliative, and surgical interventions primarily aimed for pain management and improvement of function. After tumor resection and reconstruction of the distal and diaphyseal femur (Fig. 3), mobilization of the knee joint with free range of motion was initiated at the second week postoperatively. 1.5 years after surgery the patient showed only 10° flexion of the knee joint and a LLD of 3 cm, equalized by shoe lifts, but was nevertheless able to ambulate independently and free of pain. Due to tumor dissemination, the patient ultimately succumbed to disease 15 months after tumor resection.

4.4. Case # 4

A male patient with Ewing's sarcoma of the right distal Femur received tumor resection and reconstruction of the diaphysis and distal femur at the age of 4 years. 45° flexion of the knee joint was achieved 1 week postoperatively, and 90° at the second postoperative week. Full weight-bearing was allowed 6 weeks postoperatively.

To date, 1 revision surgery with exchange of modular components has been performed. At the time of last follow-up at our outpatient clinic, 4 years after initial surgery, the patient showed a LLD of 2 cm (Fig. 4) and 90° flexion of the knee joint. The patient was able to ambulate independently without shoe lifts or walking aids. The MSTS score was 24 points at the time of last follow-up.

4.5. Case # 5

A male patient was diagnosed with Ewing's sarcoma of the left femur at the age of 1 year. Tumor resection and total femur reconstruction was performed at 1.5 years of age. At the time of surgery, the patient had not yet made any attempts to start walking. The initial reconstruction of the distal femur was achieved with an inverse humerus cap while a cementless glenoid combined with a 40 mm glenosphere was used as a tibial plateau (implantcast GmbH, Buxtehude, Germany). Diaphyseal reconstruction was performed with an off-label use of an obeslisc™ distractable vertebral body replacement (ulrich medical, Ulm, Germany), in order to be able to perform subsequent revision surgeries for lengthening minimally-invasive. A long leg cast with a pelvic band was applied for 4 weeks postoperatively to allow soft tissue remodeling around the knee. 2 months after the initial surgery the patient presented with deep infection, requiring revision surgery. Intraoperatively, the decision was made to perform exchange of the prosthesis due to loosening. Reconstruction of the knee joint was conducted by implantation of a 50 mm distal humerus, while a cementless ulna anchorage stem served as a tibial plateau. Diaphyseal reconstruction was performed with a 10 mm reducer and a 75 mm MUTARS® bar screw (Fig. 5).

Table 1
Patient data.

Patient	Age at surgery (years)	Sex	Diagnosis	Tumour resection	Revision surgeries	Follow-up (years)	LLD at last follow-up (cm)	MSTS score at last follow-up (points)
1	3	female	Ewing's sarcoma	Total femur	6	8	13.5	21
2	8	female	Osteosarcoma	Distal femur	1	3	3	24
3	4	male	Osteosarcoma	Distal femur	0	*deceased*	3	18
4	4	male	Ewing's sarcoma	Distal femur	1	3	2	24
5	1.5	male	Ewing's sarcoma	Total femur	1	1.5	5.5	12

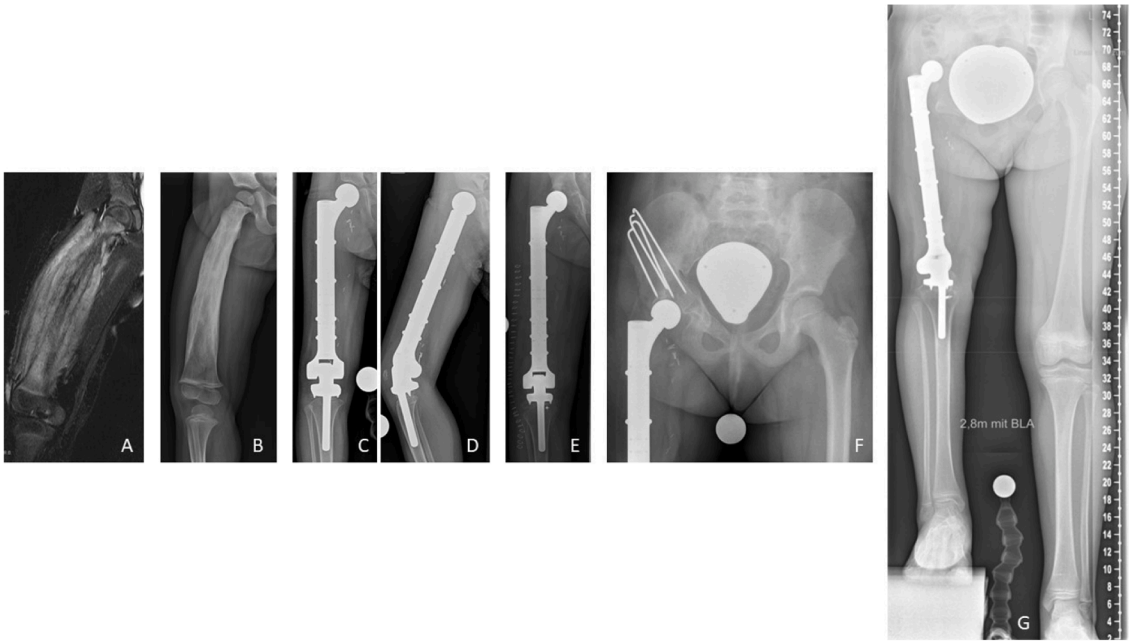

Fig. 1. Patient 1. Female patient with Ewing's sarcoma of the right femur (A. MRI, coronal view; B. radiograph, anteroposterior (a.p.) view). Total femur resection and MUTARS® Humero pro Femur reconstruction at the age of 3 years (C. a.p. view; D. lateral view). First revision with 10 mm lengthening of the modular prosthetic system 3 years after the initial surgery (E.). 5 years after tumor resection a triple osteotomy of the right pelvis was performed (F.). At the time of last follow-up at the age of 12 years the patient showed a remaining LLD of 13.5 cm (G.).

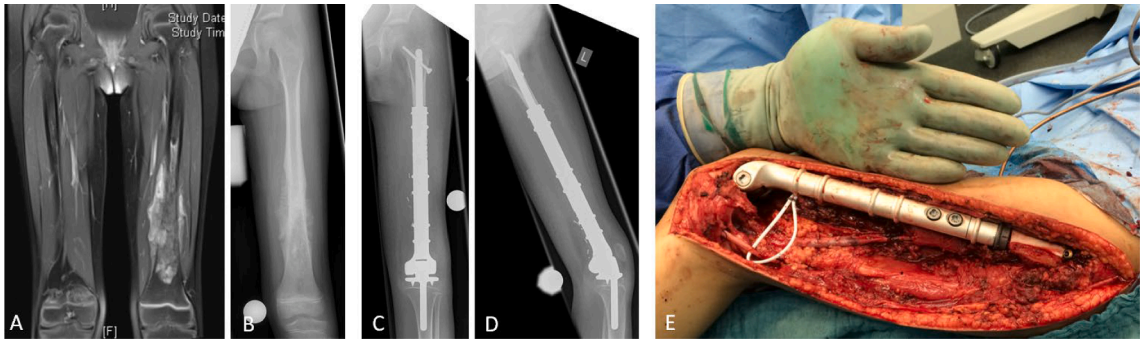

Fig. 2. Patient 2. Female patient with osteosarcoma of the left distal femur (A. MRI, coronal view; B. radiograph, a.p. view). Tumor resection and reconstruction of the distal femur and diaphysis was performed at the age of 8 years (C. a.p. view; D. lateral view; E. intraoperative view of the femoral reconstruction).

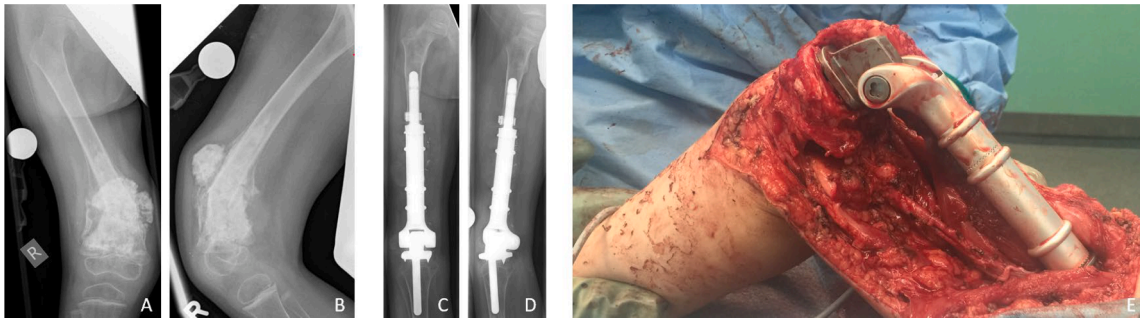

Fig. 3. Patient 3. Male patient with osteosarcoma of the right distal femur, presenting with pathological fracture of the distal femur at the time of initial consultation (A. a.p. view; B. lateral view). MUTARS® Humero pro Femur reconstruction was performed at the age of 4 years (C. a.p. view; D. lateral view; E. intraoperative view of femoral reconstruction).

Physiotherapy was commenced at the third postoperative week with free range of motion.

At the time of last follow-up, 1.5 years after the initial surgery, the patient presented with a LLD of 5.5 cm, a maximum flexion of the knee joint of 10° and drop foot. The MSTS score was 12 points. However, the patient had started walking with the help of a posterior walker and was

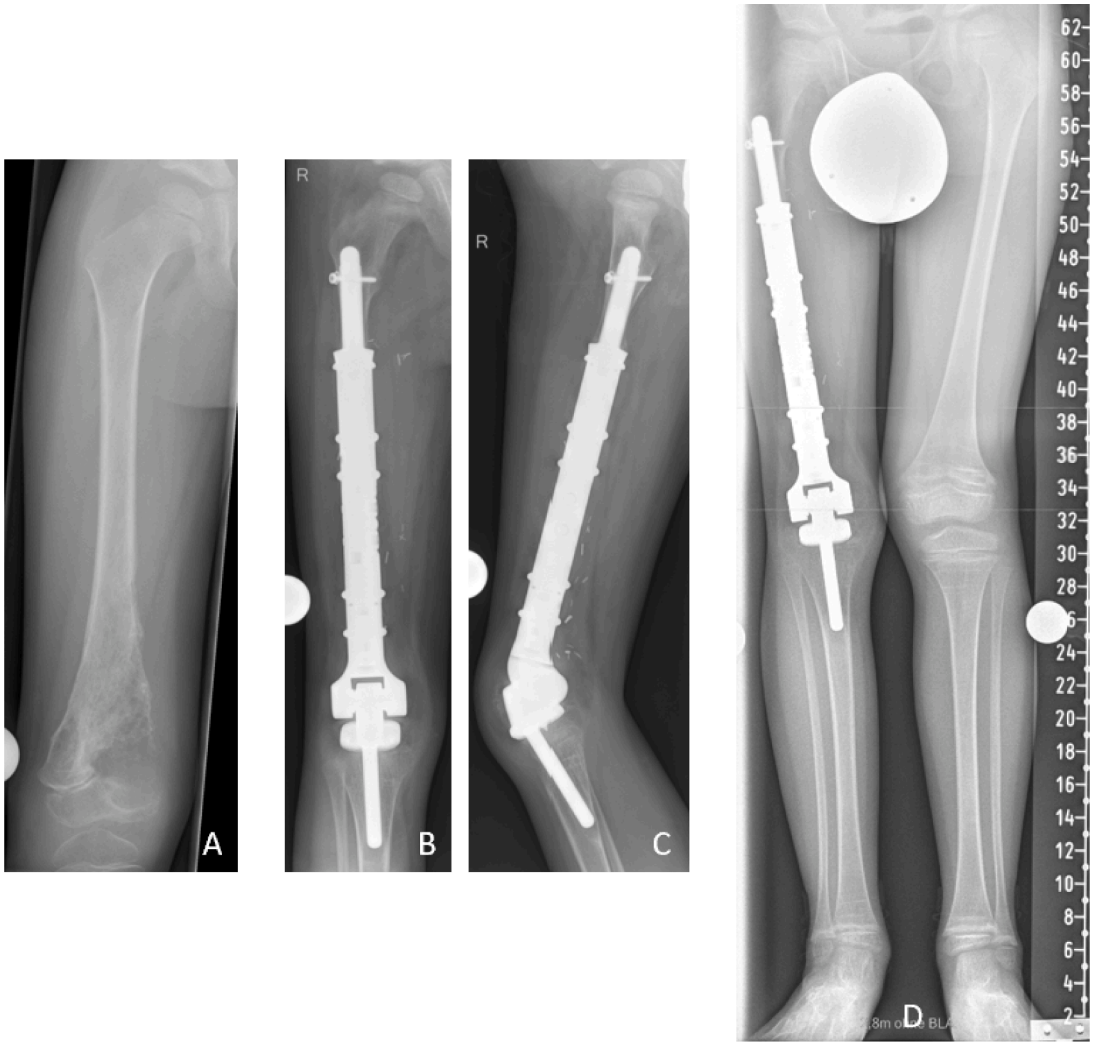

Fig. 4. Patient 4. Male patient with Ewing's sarcoma of the right distal femur (A. a.p. view). MUTARS® Humero pro Femur reconstruction was performed at the age of 4 years (B., C. 2 years postoperatively, a.p. (B.) and lateral (C.) views). 2.5 cm LLD 3 years postoperatively (D. a.p. view).

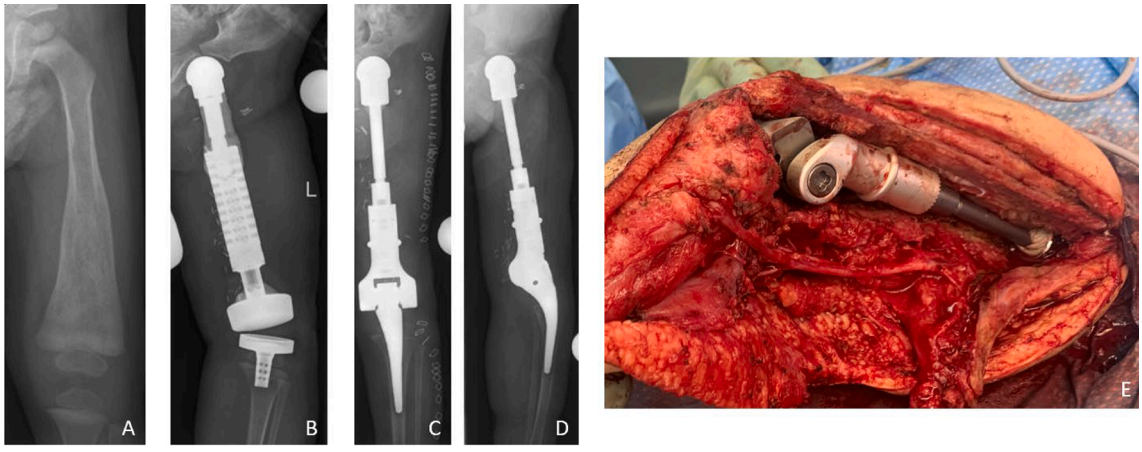

Fig. 5. Patient 5. Male patient with Ewing's sarcoma of the left femur (A. a.p. view). After total femur resection, diaphyseal reconstruction was performed with a distractable vertebral body replacement, while the knee joint was reconstructed with an inverse humerus cap, a glenoid and a 40 mm glenosphere (B. a.p. view). 2 months after the initial reconstruction a revision surgery was performed with exchange of the prosthesis and implantation of a MUTARS® Humero pro Femur replacement; in this case, an ulna anchorage stem served as a tibial plateau (C. a.p. view; D. lateral view; E. intraoperative view of the femoral reconstruction).

free of pain and with no signs of local tumor recurrence.

5. Review of the literature

Various ablative as well as reconstructive approaches have been established for treatment of malignant bone sarcomas of the femur. Ablative procedures generally produce reliable results, in particular regarding oncological resection margins. However, even though the functional outcome especially after rotationplasty is mostly satisfying, these procedures imply life-long dependence on exoprostheses and may result in a negative psychofunctional impact on the patient, and are thus often refused by the parents [8,9]. Biological reconstruction through allograft or autograft replacement represents the most commonly used treatment approach in young children [10]. Autografts offer the advantage of precise dimensions required for reconstruction as well as preservation of muscle attachments, but application is limited to non-osteolytic bone tumors [11–13]. Furthermore, procedures for devitalization of the tumor bearing bone segment such as extracorporeal irradiation [13], freezing [11,14] or autoclaving [13] alter bone morphology. Hence the capacity for biological remodeling is diminished, which may affect the graft-host bone incorporation [11,13]. Moreover, after reimplantation of devitalized tumor bearing bone there is persistent risk of graft-derived tumor recurrence [11,13], and the lack of tissue for histopathological examination to determine resection margins as well as the response grade according to Salzer-Kuntschik [15] and Huvos [16] complicates the establishment of adjuvant treatment protocols [13].

Regarding allograft reconstruction, adequate doner bones are not available in many countries, and there is a considerable risk for infection, fracture, and non-union [13,17–22]. Moreover, complication rates of allograft reconstruction are even higher in children [6].

In recent decades, limb-preserving reconstruction with tumor endoprostheses has become the most commonly used reconstructive approach in treatment of malignant bone sarcomas, avoiding many of the aforementioned complications [23]. Functional results are generally satisfying, and in particular prostheses with silver-coated surfaces have shown decreased infection rates [24,25].

In children and adolescents, reconstructive treatment has to take the occurrence of LLD into account, in particular when resection of the growth plate is required to achieve tumor free resection margins. LLD of 3 cm or less are generally treated non-operatively or by contralateral epiphysiodesis [1]. Alternatively, implantation of an oversized tumor endoprosthesis can be considered to regain equalized limb length with sustained growth of the contralateral leg [1]. The application of growing prosthesis, on the other hand, may be considered in LLD of 3 cm or more [1,4]. Even though the functional outcome of expendable endoprostheses is generally satisfying, infection rates remain relatively high even in prostheses which can be lengthened non-invasively, ranging from 11% to 47% [1,4,26,27]. Furthermore, owing to the lengthening mechanism growing prostheses are prone to mechanical failure [1]. The lengthening capacity of most growing prosthesis is dependent on their size, which in turn has to be adapted to the length of the resected bone segment. Hence, the lengthening capacity of extendable prostheses is generally limited in children of 7 years or younger [1]. This implies the requirement for one or multiple revision surgeries with exchange of modular components to address severe LLD, which – in particular in case of total femur resection – may easily exceed 10 cm [1]. Moreover, application of tumor prostheses is often unfeasible in young children due to inadequate bone dimensions and an insufficient soft tissue envelope.

In case of non-applicability of the aforementioned treatment procedures, the off-label use of a MUTARS® distal humerus for Humero pro Femur replacement represents an alternative approach for limb-preservation after resection of bone sarcomas of the femur in young children. Thus far, our findings show reasonable complication rates but varying functional results. To address LLD occurring during sustained growth, revision surgeries may be performed for lengthening through exchange of modular components. In this way, the time until implantation of an extendable prosthesis becomes feasible can be bridged. By application of a tibial plateau with a polished stem the proximal tibial physis can be spared, avoiding further increase of LLD [28,29]. Furthermore, exchange to an osteointegrative modular tibial plateau can be performed after skeletal maturation [1]. However, it should be noted that application of the MUTARS® Humero pro Femur procedure for total femur reconstruction is associated with an increased number of revision surgeries, as pronounced LLD due to resection of both the proximal and the distal femoral physis may require revision for lengthening. Furthermore, total femur reconstruction in young children may result in hip dysplasia and consecutive dislocation of the hip joint, consequently requiring pelvic osteotomy to regain sufficient hip containment [1]. Moreover, the risk of periprosthetic joint infection is considerably higher in megaprostheses [3], and may ultimately lead to implant failure and secondary amputation.

6. Conclusions

MUTARS® Humero pro Femur replacement represents a salvage procedure for limb-preserving treatment in young children in whom conventional reconstructive approaches after bone sarcoma resection of the femur are not feasible. This procedure allows bridging until sufficient bone dimensions and soft tissue coverage for implantation of a modular tumor prostheses or extendable prostheses are achieved. The preliminary complication rates seem to be reasonable, while sufficient functional results were not achieved in all patients. Moreover, subsequent surgeries to address occurring LLD have to be anticipated and are even more likely in case of total femur reconstruction. Further evaluations will have to investigate the long-term outcome of this novel treatment regimen.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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