



High complication and revision rates after total femoral replacement: a retrospective single center analysis of indication, function, and complication

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Received: 19 August 2018 / Published online: 28 January 2019
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Abstract

Introduction Total femoral replacement (TFR) is a limb salvage procedure performed for large bony defects. However, it is often associated with major complications and reduced function. Data on limb preservation rates and functional outcomes after TFR are limited. The primary objective of this study is to assess indications, functional outcomes, and complications after TFR.

Materials and methods We retrospectively analyzed all patients after TFR between 2006 and 2016. All patients received a modular mega endoprosthesis (MUTARS[®]). Patients were grouped according to their initial indication for TFR: (1) fracture, (2) tumor, or (3) infection. We evaluated (i) patient survival, (ii) postoperative function with the Musculoskeletal Tumor Society Score (MSTS), knee strength, range of motion, and (iii) complications.

Results Between 2006 and 2016, TFR was performed in 22 patients with a mean age of 64 +/- 17 years. Indications for TFR were tumor ($n=6$), infection ($n=8$) and fracture ($n=8$). The mean follow-up (f/up) was 18 months. At final follow-up, mean MSTS was 24%. Mean knee flexion strength was reduced 63% compared to the contralateral leg ($p=0.004$). At time of final f/up, 5 patients (22%) died, 5 (22%) underwent secondary hip exarticulation, and 12 (54%) suffered a major complication. At f/up, 11 patients had infections. Of these 11 patients, 5 died, 4 were treated with debridement, and 5 were treated with hip exarticulation. Fifteen patients survived with preserved limbs at f/up.

Conclusion TFR is a salvage procedure with limited functional outcome and high complication rates. Nevertheless, the majority of our cohort could be treated successfully with limb salvage.

Keywords Total femoral replacement · Outcome · Indication · Function · Complication

Introduction

The first total femoral replacement (TFR) was implanted in 1965 by Joseph Buchman [1]. Indications for TFR as a salvage operation are large bone defects, usually after tumor resection, periprosthetic loosening, periprosthetic fracture,

primary complex fracture, periprosthetic infection, pseudarthrosis, or recurrent prosthetic instability [32]. In Germany, approximately 7500 patients per year undergo major amputations for trauma, soft tissue injury, and tumor [20, 29]. Periprosthetic fractures with large bone defects range between 0.3 and 5.5% after primary total knee arthroplasty

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and are seen in up to 30% after revision arthroplasty with mortality rates as high as 46% [15, 16]. For periprosthetic fractures or bone defects at the proximal femur, the MUTARS® system (Implantcast GmbH, Buxtehude, Germany) is a well-established system; however, it is associated with high reoperation rates, up to 25% [4]. Although TFR offers the opportunity to return to daily living, they are associated with major complications and revision rates as high as 59% [2, 3, 9, 25]. The main cited complication is a high infection rate, up to 34%, compared with primary prosthetic joint replacements [5–8, 14, 27, 32], likely due to longer surgery time, larger soft tissue damage, complex biomechanical reconstruction, and larger prosthetic surface area [8]. The total postoperative complication rates ranges from 25 to 92% [8], primarily in the TFR cohort after tumor resection.

Functional outcome after TFR is guarded [17, 22]. Although the complications and revision rates are high, alternative treatment options are often limited to above-knee amputation or even hip exarticulation [21]. Prior studies have focused on young oncologic cohorts, whereas we treat a more heterogeneous patient cohort at our Trauma Center. The primary objective of this study is to determine the indications, functional outcomes, and complications of a cohort of patients who underwent TFR. We hypothesize that (1) implantation of TFR is associated with severely impaired clinical function compared to the contralateral side, (2) operative time, age, and ASA classification are risk factors for postoperative complications, and (3) postoperative infections are associated with worse clinical outcomes, higher revision rates, and secondary limb loss.

Materials and methods

This study was performed with institutional review board approval. We retrospectively analyzed all patients at our Trauma Center and Department of Musculoskeletal Tumor Surgery who underwent TFR between 2006 and 2016. We used a modular mega endoprosthesis system for TFR (MUTARS®) in all patients. This modular universal tumor and revision system allows for modular total femur reconstruction, including a hip replacement, adjustable femoral shaft modules, and a rotating hinged total knee replacement. We evaluated: (i) indication for TFR, (ii) postoperative function, and (iii) complications such as postoperative infection and revision surgery. Indications for TFR were classified into three groups: (1) trauma, (2) tumor, and (3) infection. Postoperative function was assessed by the Musculoskeletal Tumor Society Score (MSTS) [3], final hip and knee ranges of motion (ROM), and final knee flexion (N) and extension (kg) strengths.

Demographic patient data were queried from our hospital registry and were retrospectively analyzed for the aforementioned variables. Initial query resulted a cohort of 22 patients who underwent TFR.

Clinical evaluation was performed in our outpatient clinic. We assessed MSTS, ROM, and strength. An orthopaedic surgeon who was blinded for the initial indication and patient's history performed clinical examination of hip and knee ROM. A blinding for the operated extremity was not performed. For patients who could not come to an office visit, we assessed functional ability via telephone interview or used the last documented ROM in the patient record. We used the German translation of the Musculoskeletal Tumor Society Score (MSTS) for the lower extremity (Enneking), which ranges from 0 to 30 and addresses pain, function, emotional situation, medical aids, walking distance, and gait to evaluate the subjective clinical function. High values indicate better and low values indicate worse functional outcomes. Patients were asked to complete the MSTS either before clinical evaluation or by telephone or mail questionnaire. Two orthogonal plain radiographs were performed of the hips, femurs, and knees and were evaluated for signs of osteolysis, heterotopic bone formations, or tumor recurrence. Furthermore, muscle strength was measured for knee extension and flexion. For knee extension strength, we used a knee-trainer device [12, 30], which asks patients to press against a hypomochlion beneath the popliteal fossa and measures muscle strength in kilograms (kg). For knee flexion strength, we used the IsoForceControl® (MDS AG; Oberburg, Switzerland) device, which asks patients to flex their knee with full power and measures the bending strength of the knee in Newtons (N).

To rule out infection, we used intraoperative and postoperative microbial probes and diagnosis was based on international consensus for the diagnosis of periprosthetic infection.

As the trial was of exploratory nature no sample size calculation was performed. Data were summarized using Microsoft Excel® software and statistical analysis was performed with IBM SPSS Statistics® Version 25. Data were tested for normal distribution with the Kolmogorov–Smirnov Test. For comparative statistics *t* test, Mann–Whitney *U* test and Chi-square test were used. In case of normal distribution parametric *t* test was used. The Mann–Whitney *U* test was used for comparison of nonparametric unpaired variables between groups. Regression analysis was used for multivariate analysis. The standard significance criterion of $\alpha=0.05$ was employed. Data are expressed as mean +/- standard deviation.

Results

Study cohort

In total, between 2006 and 2016, TFR was performed in 22 patients with a mean age of 64 years (range 22 to 85 years), including 13 female (59%) and 9 male (41%) patients. No intramedullary femur replacements were used. The mean ASA classification was 2.5 (range 0–4). TFR was performed in six patients for tumor, eight patients for periprosthetic infection, and eight patients for periprosthetic fracture. The mean follow-up was 18 months (\pm 21 months). There was no statistically significant difference between the three groups for age or ASA classification (Table 1).

Functional outcomes

In the study cohort, at final follow-up, mean hip flexion was $82 \pm 19^\circ$ and mean knee flexion was $81 \pm 20^\circ$. Mean hip flexion was $92 \pm 3^\circ$ in the tumor group, $90 \pm 0^\circ$ in the infection group, and $65 \pm 25^\circ$ in the fracture group. Mean knee flexion was $82 \pm 23^\circ$ in the tumor group, $85 \pm 16^\circ$ in the infection group, and $76 \pm 19^\circ$ in the

fracture group. There was no statistically significant difference between the three subgroups with respect to postoperative hip or knee ROM. However, the trauma group showed a trend to decreased ROM compared to the remaining cohort. Knee extension strength was comparable to the contralateral side ($p=0.2$). However, a significant reduction in knee flexion strength, to 37% of the contralateral side, was observed ($p=0.004$). The mean MSTS score was 7.2/30, with no significant difference among the three groups.

Complications

We observed 12 major complications, including 1 prosthetic hip joint dislocation and 11 periprosthetic infections. Out of these, 10 underwent revision surgery. One patient was treated conservatively for persistent low-grade infection without revision surgery due to the high morbidity of reoperation. There was a high correlation between revision surgery and infection ($p=0.002$). However, the infection rate did not correlate with age or ASA classification. Of the 8 patients who received TFR for infectious indications, 3 patients had no signs of infection postoperatively, whereas 5 patients developed recurrent or new infection, despite negative preoperative microbial probes. New postoperative infections

Table 1 Patients characteristics from the 22 patients included in the study

Sex/age	Knee ROM ($^\circ$)	Hip ROM ($^\circ$)	Indication	Revision (<i>n</i>)	Infection	Operative time (min)	ASA classification
F/82	0/0/50	0/0/90	Infection	–	–	237	2
M/81	0/0/90	0/0/90	Infection	–	–	425	2
F/60	0/0/90	0/0/90	Infection	Debridement	Yes	225	2
M/60	0/0/90	0/0/90	Infection	–	Yes	359	2
F/73	Exarticulation	Exarticulation	Infection	Exarticulation	Yes	390	2
F/68	5/0/105	0/0/90	Infection	Debridement	–	298	3
M/58	0/10/90	0/0/90	Infection	Cup change	Yes	440	4
F/74	Dead	Dead	Infection	Exarticulation	Yes	225	3
M/71	0/5/30	0/0/90	Spindle-cell sarcoma	–	–	393	3
M/74	0/0/95	0/0/90	Chondrosarcoma	–	–	338	2
M/69	0/0/90	0/0/95	Metastatic carcinoma	–	–	460	4
M/22	0/0/90	0/0/100	Ewing sarcoma	–	–	387	2
F/42	0/0/90	0/0/90	Metastatic carcinoma	1	Yes	380	2
M/29	0/0/100	0/0/90	Osteosarcoma	–	–	410	1
F/62	0/0/90	0/0/90	B2 periprosthetic fracture	–	–	255	3
M/52	0/0/90	0/0/90	C periprosthetic fracture	3, Exarticulation	Yes	291	3
F/74	0/0/90	0/0/60	B2 periprosthetic fracture	–	–	364	2
F/77	0/0/60	0/0/60	C periprosthetic fracture	2	Yes	207	3
F/85	0/0/90	0/0/80	atypic	–	Yes	323	2
F/85	Exarticulation	Exarticulation	B2 / 2 periprosthetic fracture	1	Yes	221	3
F/79	0/30/40	0/0/15	B2 periprosthetic fracture	–	–	199	4
F/45	Explantation/ dead	Explantation/ dead	B2 / 3 periprosthetic fracture	1	Yes	225	3

F Female, M male, ROM range of motion Vancouver classification/Rorabeck classification for periprosthetic fracture

developed in six patients who underwent TFR for noninfectious indications. At final follow-up, 5 patients died, and 5 patients underwent hip exarticulation. Of those with postoperative infection ($n = 11$), 5 died (45%) and 5 (45%) underwent hip exarticulation. A total of 15 (68%) patients maintained their limbs and are still alive. Of the 5 dead patients, none were from the tumor group, 2 were from the fracture group, and 3 were from the infection group. Although there was no statistically significant difference in regard to mortality between the three groups, there was a trend to a higher mortality in the infection group with 42% compared to the trauma group with 22% and the tumor group with 0%. The mean operative time was 320 min (range 199–420 min). Although the operative time in the tumor group was significantly longer compared to the trauma group ($p = 0.001$), this parameter did not correlate with higher infection rates. There was no difference in mean operative time in those with a postoperative infection (289 \pm 79 min) and those without a postoperative infection (342 \pm 80 min) ($p = 0.2$) (Figs. 1, 2, 3).

Discussion

The indications for TFR are rare, and data on functional outcomes of TFR are limited, especially after periprosthetic fracture and periprosthetic infection. We confirmed the hypothesis that implantation of TFR is associated with a highly limiting clinical function compared to the contralateral side and found a significant reduction in knee extension and flexion strength compared to the contralateral side. Contrary to our expectations, age, ASA classification, and operative time are not associated with postoperative complications; however, postoperative infections are associated with higher revision rates. TFR is still a limb salvage procedure and especially after infection with a trend to a higher mortality it should be considered carefully.

Our mean MSTS score of 24% (7.2/30) is inferior compared to prior reports in the literature [18, 22, 26]. However, prior studies included only young patients with a mean age of 30 to 31 years [13, 18, 20, 22] and our cohort was much older. Moreover, prior studies focused on oncologic patients, whereas our patient's cohort was mixed and consisted of only 6 oncologic patients with an additional 16 cases with history of several previous operations and subsequent poor soft tissue conditions.

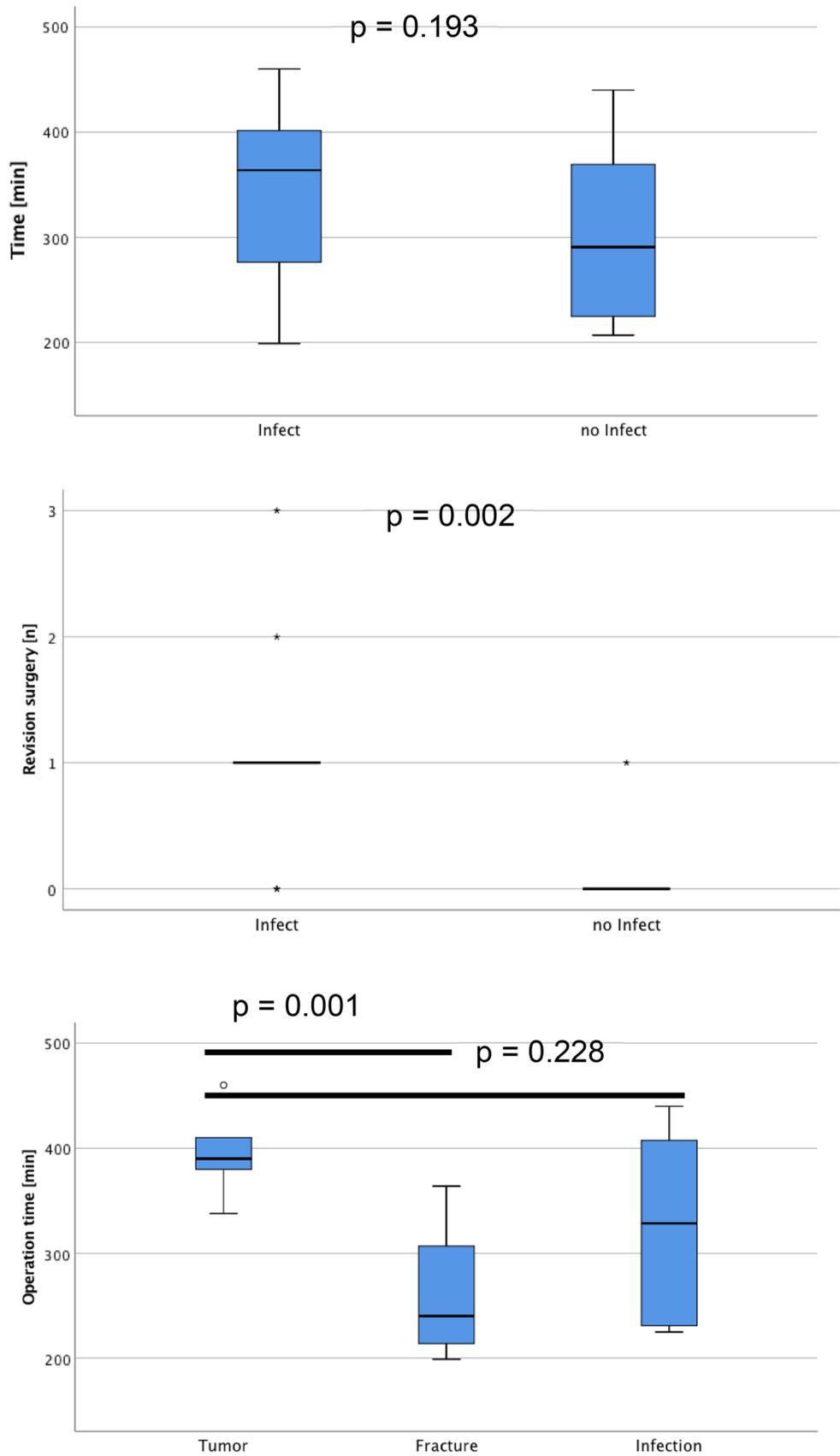
Our reported knee and hip ROM were comparable to those reported in the literature [22]. Limited data exists to describe functional outcomes after TFR; therefore, we further measured knee flexion and extension strengths. The observed mean reduction of the extension strength to 63% compared with the contralateral side, although not statistically significant, was likely a side effect of the surgical

procedure. Knee extension forces are transferred through the patellar tendon to the tibia which is generally preserved and untouched. The reduction of extension force may be due to loss of femoral length and reduced muscle preloading. Moreover, reduced limb use leads to muscle atrophy and additionally attenuates muscle strength. Significant reduction of knee flexion strength may also be related to loss of femoral length and muscle disuse atrophy. Furthermore, systematic release of the gastrocnemii muscle from the posterior distal femur is an additional contributor to the loss of flexion power resulting in mean reduction of knee flexion strength to 38% of the contralateral side.

Our observed infection rate of 50% is higher than the cited value in the literature of approximately 34% [9, 10]. This is likely due to the high rate of preoperative periprosthetic infection, which was present in 8 patients. Despite negative preoperative microbial probes, the risk of persistent periprosthetic infection is high, especially after megaprosthesis implantation. However, our revision surgery rate of 45% was slightly below the reported average of 59% [3, 9, 25]. We expected a worse clinical outcome and higher infection and revision rates with increasing age and ASA classification, but neither age nor ASA classification were associated variables in this study cohort. The operative time in the tumor group was significantly longer compared to the trauma group, likely due to a more time-consuming and meticulous wide tumor resection. However, there was no significant correlation between operative time and rates of infection.

Data on complication rates are heterogeneous as shown by Hoell et al. [11] who observed a complication rate of only 4% after TFR in 12 patients and 33% after intramedullary femur replacement and no recurrence of infection after TFR implantation in 5 patients after preoperative periprosthetic joint infection. Although our data are above the given complication rate they are in line with the data given by Toepfer et al. who evaluated 22 patients and had a revision rate of 59% with 5 infections. Taking into consideration that a major difference between both groups was that we included patients after periprosthetic joint infection, higher rates in our cohort can be explained thereby. However, the indication should be considered carefully in close discussion with the patient especially after periprosthetic joint infection. The option of a lower level disarticulation or amputation should be considered, and the high revision rate should be explained to the patient. If considering a TFR into a formerly periprosthetic joint infection an extensive debridement should be performed, and a perioperative antibiotic therapy should be performed as described by Renz et al. Additionally, an antibiotic long-term therapy should be considered in case of complicated infection and chronic infection [23]. General factors influencing the risk of revision surgery due to

Fig. 1 Operative time did not correlate with the infection rate. The revision rate was significantly higher if an infection was present. The operative time in the tumor group was significantly longer compared with the fracture group, but not with the infection group



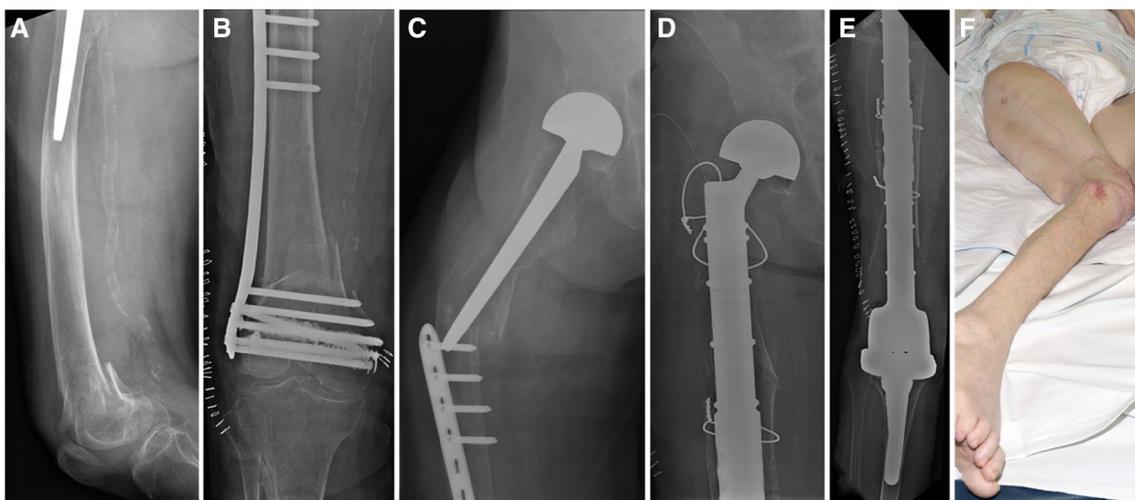


Fig. 2 79-years-old female patient first presenting in our emergency room with a 33-A3 fracture of the distal femur and bad bone stock (**a**). A cement augmentation and LISS fixation was performed (**b**). We had to observe a periprosthetic fracture (**c**). Therefore, we needed

to revise the patient and total femur replacement was performed (**d**, **e**). Although postoperative X-ray showed good results we needed to observe a discrepancy compared to the clinical outcome (**f**)

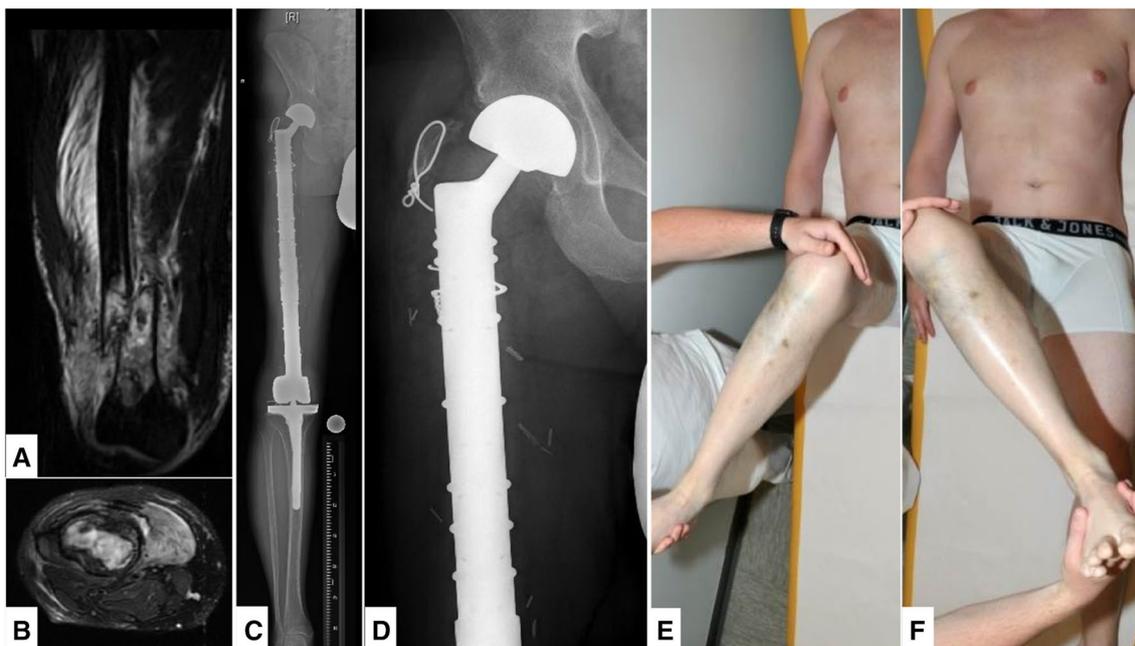


Fig. 3 29 years old male patient who needed to undergo total femur replacement in a case of osteosarcoma in 02/2012 as shown in **a** (MRI scan coronal T2) and **b** (MRI scan axial T2 fat saturated). At

5-year follow-up in 05/2017 the patient showed no signs of tumor relapse or implant associated problems (**c**, **d**). He presented without pain and only minor functional impairment (**e**, **f**)

a periprosthetic joint infection are male sex, younger age, elevated BMI and diabetes [17]. Apart from this factors and most importantly previous septic arthritis influences the risk of revision surgery [17]. To reduce the risk of an infection during initial operation silver coating has been shown to be a valuable tool [24]. Data on silver coating during revision surgery are so far not distinct, however

silver coating seems to positively influence the postoperative infection rate [28, 31]. Further options could be the use of an antibiotic-loaded hydrogel which has been shown to reduce the infection rate after internal osteosynthesis [19]. So far data on the impact after periprosthetic joint infection is missing and needs to be evaluated in the future.

Limitations

One major limitation is the heterogeneous and small sample size which could be expected for a single center analysis. Furthermore, variables as different surgeons, type of microbial colonization, antibiotic therapy might have influenced the outcome. We performed a post hoc power analysis with a power between 24 and 44%. We are aware of the given, very low values. A sample size of 50 patients for each group would have been needed to answer our questions more reliable. Nevertheless, our data give general information about the outcome after TFR in a heterogeneous collective and are in accordance with the data given by Toepfer et al.

Conclusion

In our heterogeneous patients group after TFR, limb salvage was successful in 68% of patients. This was associated with a significant loss of function compared to the contralateral side, especially for knee flexion strength, which reduced to 38% of normal. We observed high infection rates in our cohort, up to 50%, which did not correlate with age, ASA classification, or operative time. TFR is a suitable limb salvage procedure, but surgeons should be aware of high complications and revision surgery rates. Therefore, we recommend a strict evaluation of indications and balanced consideration of alternative treatment options before total femur replacement. There is a need for multicenter studies to risk-stratify potential candidates for TFR and to identify parameters which make TFR a more favorable option to allow limb salvage while preserving maximal function.

Compliance with ethical standards

Conflict of interest All authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. For this type of study formal consent is not required.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

- Buchman J (1965) Total femur and knee joint replacement with a vitallium endoprosthesis. *Bull Hosp Jt Dis* 26:21–34
- Clement ND, MacDonald D, Ahmed I, Patton JT, Howie CR (2014) Total femoral replacement for salvage of periprosthetic fractures. *Orthopedics* 37(9):e789–e795. <https://doi.org/10.3928/01477447-20140825-55>
- Enneking WF, Dunham W, Gebhardt MC, Malawar M, Pritchard DJ (1993) A system for the functional evaluation of reconstructive procedures after surgical treatment of tumors of the musculoskeletal system. *Clin Orthop Relat Res* 286:241–246
- Gebert C, Wessling M, Götze C, Gosheger G, Harnes J (2010) The modular universal tumour and revision system (MUTARS®) in endoprosthesis revision surgery. *Int Orthop* 34:1261–1265
- Gerdesmeyer L, Töpfer A, Kircher J, Grundei H, Diehl P (2006) The modular MML revision system in knee revision and tumor arthroplasty. *Orthopade* 35:975–981
- Gosheger G, Gebert C, Ahrens H, Streitbueger A, Winkelmann W, Harnes J (2006) Endoprosthesis reconstruction in 250 patients with sarcoma. *Clin Orthop Relat Res* 450:164–171
- Gradinger R, Gollwitzer H (2006) Spezialimplantate—Tumorendoprothetik. *Ossäre Integration* Springer, Heidelberg, pp 180–189
- Heisel C, Kinkel S, Bernd L, Ewerbeck V (2006) Megaprotheses for the treatment of malignant bone tumours of the lower limb. *Int Orthop* 30:452–457
- Henderson ER, Groundland JS, Pala E, Dennis JA, Wooten R, Cheong D, Windhager R, Kotz RI, Mercuri M, Funovics PT, Hornicek FJ, Temple HT, Ruggieri P, Letson GD (2011) Failure mode classification for tumor endoprotheses: retrospective review of five institutions and a literature review. *J Bone Jt Am* 93:418–429
- Henderson ER, O'Connor M, Ruggieri P, Windhager R, Funovics PT, Gibbons CL, Guo W, Hornicek FJ, Temple HT, Letson GD (2014) Classification of failure of limb salvage after reconstructive surgery for bone tumors: a modified system including biological and expandable reconstructions. *Bone Joint J* 96:1436–1440
- Hoell S, Butschek S, Gosheger G, Dedy N, Dieckmann R, Henrichs M, Daniilidis K, Harnes J (2011) Intramedullary and total femur replacement in revision arthroplasty as a last limb-saving option: is there any benefit from the less invasive intramedullary replacement? *J Bone Jt Surg Br* 93:1545–1549
- Horstmann H, Colcuc C, Lobenhoffer P, Krettek C, Weber-Spickschen TS (2017) Evaluation of the acceptability of a sphygmomanometer device in knee extension training following surgical procedures of the knee. *Int J Orthop Trauma Nurs* 25:42–47
- Jones KB, Griffin AM, Chandrasekar CR, Biau D, Babinet A, Dehesi B, Bell RS, Grimer RJ, Wunder JS, Ferguson PC (2011) Patient-oriented functional results of total femoral endoprosthesis reconstruction following oncologic resection. *J Surg Oncol* 104:561–565
- Kinkel S, Lehner B, Kleinhans JA, Jakubowitz E, Ewerbeck V, Heisel C (2010) Medium to long-term results after reconstruction of bone defects at the knee with tumor endoprotheses. *J Surg Oncol* 101:166–169
- Knight SR, Aujla R, Biswas SP (2011) Total hip arthroplasty—over 100 years of operative history. *Orthop Rev (Pavia)* 3:16
- Kösters C, Stange R, Raschke MJ (2012) Periprothetische Frakturen bei Knieendoprothese. *Trauma Berufskrankheit*. <https://doi.org/10.1007/s1003901218981>
- Lenguerrand E, Whitehouse MR, Beswick AD, Kunutsor SK, Burston B, Porter M, Blom AW (2018) Risk factors associated with revision for prosthetic joint infection after hip replacement: a prospective observational cohort study. *Lancet Infect Dis* 18:1004–1014. [https://doi.org/10.1016/S1473-3099\(18\)30345-1](https://doi.org/10.1016/S1473-3099(18)30345-1)
- Natarajan MV, Balasubramanian N, Jayasankar V, Sameer M (2009) Endoprosthesis reconstruction using total femoral custom mega prosthesis in malignant bone tumours. *Int Orthop* 33:1359–1363
- Malizos K, Blauth M, Danita A, Capuano N, Mezzoprete R, Logoluso N, Drago L, Romanò CL (2017) Fast-resorbable antibiotic-loaded hydrogel coating to reduce post-surgical infection after internal osteosynthesis: a multicenter randomized controlled trial. *J Orthop Traumatol* 18:159–169. <https://doi.org/10.1007/s10195-017-0442-2>

20. Müller CW, Krettek C, Decker S, Hankemeier S, Hawi N (2016) Limb salvage or amputation after severe trauma to the lower extremities: evidence from the LEAP Study. *Unfallchirurg* 119:400–407
21. Ramanathan D, Siqueira MB, Klika AK, Higuera CA, Barsoum WK, Joyce MJ (2015) Current concepts in total femur replacement. *World J Orthop* 18:919–926
22. Ruggieri P, Bosco G, Errani C, Mercuri M (2010) Local recurrence, survival and function after total femur resection and megaprosthesis reconstruction for bone sarcoma. *Clin Orthop Relat Res* 468:2860–2866
23. Renz N, Perka C, Trampuz A (2016) Management periprotetischer Infektionen des Kniegelenks. *Orthopade* 45:65–71. <https://doi.org/10.1007/s00132-015-3217-6>
24. Schmolders J, Koob S, Schepers P, Pennekamp PH, Gravius S, Wirtz DC, Placzek R, Strauss AC (2017) Lower limb reconstruction in tumor patients using modular silver-coated megaprotheses with regard to perimegaprosthesis joint infection: a case series, including 100 patients and review of the literature. *Arch Orthop Trauma Surg* 137:149–153. <https://doi.org/10.1007/s00402-016-2584-8>
25. Toepfer A, Harrasser N, Petzschner I, Pohl F, Lenze U, Gerdesmeyer L, von Eisenhart-Rothe R (2018) Is total femoral replacement for non-oncologic and oncologic indications a safe procedure in limb preservation surgery? A single center experience of 22 cases. *Eur J Med Res* 16:5. <https://doi.org/10.1186/s40001-018-0302-4>
26. Tunn PU, Pomraenke D, Goerling U, Hohenberger P (2007) Functional outcome after endoprosthetic limb-salvage therapy of primary bone tumours - a comparative analysis using the MSTTS score, the TESS and the RNL index. *Int Orthop* 32:619–625
27. Unwin PS, Cannon SR, Grimer RJ, Kemp HB, Sneath RS, Walker PS (1996) Aseptic loosening in cemented custom-made prosthetic replacements for bone tumours of the lower limb. *J Bone Jt Surg Br* 78:5–13
28. Wilding CP, Cooper GA, Freeman AK, Parry MC, Jeys L (2016) Can a silver-coated arthrodesis implant provide a viable alternative to above knee amputation in the unsalvageable, infected total knee arthroplasty? *J Arthroplasty* 31:2542–2547. <https://doi.org/10.1016/j.arth.2016.04.009>. Epub 2016 Apr 22
29. Willy C, Krettek C (2017) Transcutaneous osseointegrated prosthesis (TOP) after limb amputation: Status quo and perspectives. *Unfallchirurg* 120:395–402
30. Weber-Spickschen TS, Colcuc C, Hanke A, Clausen JD, James PA, Horstmann H (2017) Fun during knee rehabilitation: feasibility and acceptability testing of a new android-based training device. *Open Med Inform J* 11:29–36
31. Zajonc D, Birke U, Ghanem M, Prietzel T, Josten C, Roth A, Fakler JKM (2017) Silver-coated modular Megaendoprotheses in salvage revision arthroplasty after peri implant infection with extensive bone loss - a pilot study of 34 patients. *BMC Musculoskelet Disord* 18:383. <https://doi.org/10.1186/s12891-017-1742-7>
32. Zajonc D, Zieme A, Prietzel T, Moche M, Tjepoldt S, Roth A, Josten C, Freiherr von Salis-Soglio G, Heyde C-E, Ghanem M (2016) Periprosthetic joint infections in modular endoprotheses of the lower extremities: a retrospective observational study in 101 patients. *Patient Saf Surg* 10:6