

ORIGINAL ARTICLE

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Total femur replacement: function, quality of life, and gait: a multicentric EMSOS study

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Abstract

Background Total femur replacements (TFRs) involve the replacement of the whole femoral bone, reconstruction of the hip and knee joints, and soft tissue reconstruction for function and joint stability. The aim of this multicentric European Musculo-Skeletal Oncology Society (EMSOS) study is to report on the functional outcome, quality of life, as well as gait analysis in patients with TFR.

Materials and methods Retrospective data from 12 international participating centers were collected. In total, 65 patients [median (IQR) age at surgery 40 (18–56) years, 60% male] who received a TFR owing to oncologic or nononcologic indications between 1 January 1990 and 31 March 2024 were included. Patient-related outcome measures (PROMs), range of motion (ROM) of the hip and knee, and gait videos were collected.

Results At a median (IQR) follow-up of 28 (14–126) months, the median (IQR) percentage Musculoskeletal Tumor Society (MSTS) score was 63% (43–73%), 12-Item Short-Form Health Survey (SF-12) was 70% (55–79%), Harris Hip Score (HHS) was 63% (52–77%), and Oxford Knee Score (OKS) was 63% (52–79%); the median (IQR) extension-to-flexion ROM were 80° (70–97.5°, hip) and 70° (40–90°, knee). Gait videos were available for 24/65 patients (37%). The median (IQR) total Edinburgh Visual Gait Score of the operated side was 8.5 (6–13), with deviations from norm in all patients (24/24). Compensational gait pathology on the contralateral side was detected in 23/24 patients (96%). Better outcome measures significantly correlated with younger age (all PROMs), oncologic indications (MSTS and OKS), and primary TFR implantations (MSTS).

Conclusions Moderate-to-good PROM scores are to be expected after TFR, with better outcomes in younger patients undergoing primary implantations for oncologic indications. The reported results must be appraised as best-case estimates. The recurrent gait deviations observed and the compensational gait pathology on the contralateral side should be considered in TFR aftercare, remobilization, and patient counseling.

Level of evidence Level III, therapeutic study.

Keywords Total femur replacement, Function, QoL, Gait video analyses, EVGS

Introduction

Total femur replacements (TFRs) constitute rare and complex surgeries that not include only the replacement of the whole bone but also the reconstruction of the hip and knee joints, as well as (often) soft tissue reconstruction for function and joint stability. TFRs may either be used as primary reconstructions following resection of malignant bone and soft tissue tumors, or as secondary reconstructions after failed reconstructions for

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oncological and nononcological indications with limited bone stock.

Owing to the rarity of this complex megaprosthesis, literature on the topic is scarce. This is particularly relevant considering functional outcomes following TFR. Patients with TFR present high morbidity and mortality (also, but not only, due to the oncologic indications), high failure and revision rates (up to 60%), as well as disarticulation rates of nearly 13% [1–3]. Therefore, studies assessing functional outcomes can only consider a patient subpopulation with TFR in situ: patients who are alive, retained the limb, and deambulate at last follow-up. Monocentric collectives are often insufficient in size to provide evidence or conclusions. As a result, international cooperation and multicentric studies are warranted.

Studies reporting on functional and quality of life assessments after TFR or megaprotheses of the lower limb in general are rare [2, 4–6]. Ongoing mobility limitations were detected in most patients after TFR, with 70% requiring walking aids postoperatively [5]. Moreover, reduced mobility levels after megaprotheses of the lower limb were highlighted in prior literature, with impairments correlating with pain, reduced strength, and lower physical function and performance, with notable weakness observed even in the non-operated limb [4, 6]. Further, postoperative activity scores and performance levels significantly decrease [7], while preoperative activity levels strongly predict long-term postoperative activity levels [8]. In addition, decreased work ability in physically demanding jobs [9] was reported.

Whilst some gait analyses results are available for other megaprotheses, no gait analysis data has been published so far on TFR patients. Decreased walking speed and cadence, shorter steps, pronounced gait abnormalities with greater energy expenditure, as well as longer swing and shorter stance phases were reported in revision knee prostheses and distal femur replacements [10–13]. In addition, reduced gait quality in contralateral legs were found in most patients (92%) [12].

The aims of this multicentric study are to (1) report the functional outcome and quality of life measures after TFR implanted for oncologic and nononcologic indications, (2) analyze results from gait video analysis, (3) and identify which factors may correlate with worse Patient-Related Outcome Measure (PROM) scores and gait scores.

Materials and methods

All members of the European Musculo-Skeletal Oncology Society (EMSOS) were invited to participate in this retrospective multicentric study. The inclusion of participating centers started in June 2022 and was closed in June

2024. The multicentric data gathering was terminated in January 2025.

All patients who received a TFR for oncologic or non-oncologic indications from 1 January 1990 until 31 March 2024 were included. No age (at index operation) limitation was set. A minimum follow-up of 6 months (or less if the patient died) was required. The collected data included: demographic characteristics (age, sex), case history (indication, prior surgeries, and revisions), surgical data (procedure, TFR specifications and components, and resection details in oncologic cases), major and minor complications, revisions, and mortality data. A complication was defined as major if it led to surgical implant revision. Complication types were registered marginally using the Henderson classification [14], to facilitate multicentric data gathering.

For the available and consenting patients, further functional and subjective outcomes were recorded through a study-specific follow-up. This included four Patient-Related Outcome Measure (PROM) scores as well as clinical examination [range of motion (ROM) of the hip and knee joints, given in degrees of extension-to-flexion range]. The Musculo-Skeletal Tumor Society (MSTS) score and 12-Item Short-Form Health Survey (SF-12) were chosen for general outcome and quality of life (QoL) assessment; the Harris Hip Score (HHS) and Oxford Knee Score (OKS) were used as subjective clinical performance scores. Higher PROM scores correspond to better outcome. In addition, gait videos were recorded from the patients available. Standardized instructions for the gait videos were provided to all participating centers. The gait videos were systematically and homogeneously analyzed using the Edinburgh Visual Gait Score (EVGS) by an independent observer, highly experienced in gait analysis. The EVGS comprises 17 parameters for each lower limb and evaluates movement across six sites (trunk, pelvis, hip, knee, ankle, and foot) in the coronal and sagittal gait video planes. Each parameter gets appointed with a score from 0 (norm) to 2 (severe deviation). The total score per side can range from 0 (physiological gait, norm) to 34 and can be divided as follows: mild or minimal deviation (scores, 1–5), moderate deviation (6–10), marked deviation (11–20), and severe deviation (21–34). Higher EVGS scores correspond to worse gaits.

Statistical analysis

Statistical analyses were performed with Stata Version 16.1 for Mac (StataCorp) and R version 4.4.2. Median values with respective interquartile ranges (IQR) are reported for continuous variables. Numbers are provided with valid percentages throughout the manuscript. Regarding the missing information in subgroups of the total collective, with no systematic differences between

the missing and observed values, the available data can be considered representative [15]. The four PROM scores and the total EVGS of the operated and contralateral side were analyzed with regard to the following variables: major complication, reoperation, indication, implantation type, sex, age at study-related follow-up ($\leq$ or $>$ median value), and follow-up time ($\leq$ or $>$ median value). For pairwise comparisons between binary and continuous variables, Wilcoxon-rank-sum tests were used: subgroup-specific medians and IQRs are reported. A p -value < 0.05 was considered statistically significant.

Results

Study population

Data of 143 patients with TFR from 14 international participating centers were retrospectively collected, as previously described [16]. In 89/143 patients, functional outcome measures were available. We included patients with at least three out of four of the following items available: gait video, ROM, at least one QoL PROM, and at least one subjective clinical performance PROM (Fig. 1). Finally, 65 patients from 12 international participating centers (Table 1) could be included in this study. Therefore, the functional and patient-related outcome measures herein must be considered best-case estimates, as they most likely mirror the subset of TFR patients who are alive, able to attend a study-related follow-up, and (for those with gait videos) walking independently.

Median follow-up was 28 months (IQR, 14–126 months). Median age at index operation was 40 years (IQR, 18–56 years), median age at study-related

Table 1 Participating centers in this EMSOS multicentric study and number of included patients per center

Hospital	Country	No.
Medical University Graz	Austria	6
Orthopaedic Institute Rizzoli Bologna	Italy	9
Istanbul University Hospital	Turkey	14
IRCCS University Hospital Sant'Orsola Bologna	Italy	2
LMU Clinic Munich	Germany	1
Red Cross Children's Hospital Capetown	South Africa	12
Hebrew University Medical Centers Jerusalem	Israel	2
Helsinki University Hospital	Finland	1
University Hospital of Marseille	France	3
University of Porto	Portugal	2
University Medical Center Ljubljana	Slovenja	8
Voivodeship Hospital Toruń	Poland	5

follow-up 45 years (IQR, 29–61.5 years), and 60.0% of patients were male ($n = 39/65$) (Table 2). Most patients underwent TFR for oncologic indications ($n = 46/65$, 70.8%). Of these, 41/46 (89.1%) were primary TFRs used for reconstruction following wide tumor resection, while 5/46 (10.9%) TFRs were implanted secondarily as revision procedure of a previous reconstruction (e.g., proximal femur replacement, allo-prosthetic composite). Overall, 7/46 (15.2%) were extendable growth prostheses in skeletally immature patients. Median tumor size was 31.5 cm (IQR, 21.3–37.9 cm). The remaining 19/65 TFRs (29.2%) were implanted for nononcologic indications (all revisions of prior prosthetic/osteosynthetic/biological reconstructions). Overall, 41/65 TFRs were primarily implanted (63.1%), while 24/65 were revision or secondary TFRs (36.9%). A mesh graft tube for soft tissue reattachment was used in 46.2% of patients ($n = 30$). Median length of the TFR amounted to 40 cm (IQR, 36–45 cm). Surgical outcome and implant survival data on the total TFR population ($n = 143$) were previously published [16]. Herein, we report the surgical outcome within this further analyzed subpopulation ($n = 65$).

Complications, revisions, and reoperations

Overall, 26 patients (40.0%) developed major complications leading to TFR revision. Median time to implant revision was 21 months (IQR, 8–48 months). Soft tissue complications ($n = 11$, 16.9%), structural failure ($n = 8$, 12.3%), and deep infections (i.e., periprosthetic joint infections, $n = 5$, 7.7%) were the most frequent major complications and reasons for implant revision. In one patient each, aseptic loosening (1.5%) and local tumor recurrence (1.5%) led to revision surgery. Minor complications were observed in 11 patients (16.9%), including delayed wound healing treated through surgical wound

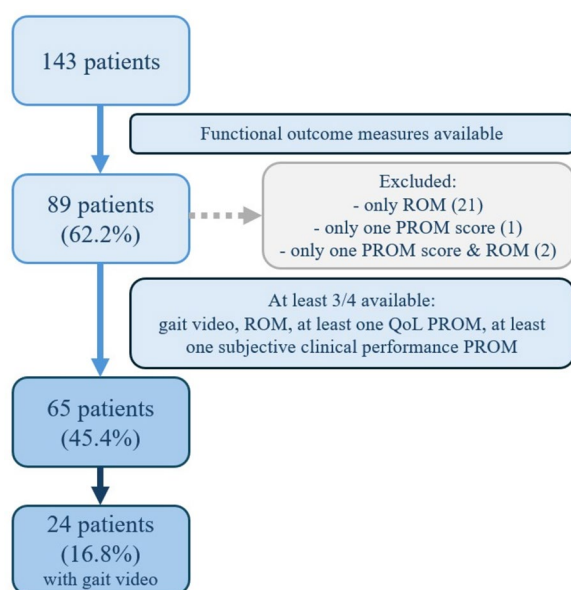


Fig. 1 Study flow chart illustrating the patient inclusion process

Table 2 Descriptive results

Variable	Value
Total no. of included patients, <i>n/N</i>	65/65 (100)
Age at surgery, median (IQR), years	40 (18–56)
Male, <i>n/N</i> (%)	39/65 (60)
Follow-up, median (IQR), months	28 (14–126)
Age at study-related follow-up, median (IQR), years	45 (29–61.5)
TFR indication	
Oncologic, <i>n/N</i> (%)	46/65 (71)
nononcologic, <i>n/N</i> (%)	19/65 (29)
TFR implantation	
Primary, <i>n/N</i> (%)	41/65 (63)
Secondary, <i>n/N</i> (%)	24/65 (37)
Major complication, <i>n/N</i> (%)	26/65 (40)
PROMs	
MSTS, median (IQR) [% median (% IQR)]	19 (13–22) [63.3 (43.3–73.3)]
SF-12, median (IQR) [% median (% IQR)]	39 (31–44) [69.6 (55.4–78.6)]
HHS, median (IQR) [% median (% IQR)]	63 (51.5–77) [63 (51.5–77)]
OKS, median (IQR) [% median (% IQR)]	30 (25–38) [62.5 (52.1–79.2)]
ROM	
Hip, median (IQR), degrees of range	80 (70–97.5)
Knee, median (IQR), degrees of range	70 (40–90)
Gait	
EVGS, operated limb, median (IQR)	8.5 (6–13)
EVGS, contralateral limb, median (IQR)	4 (2–5)

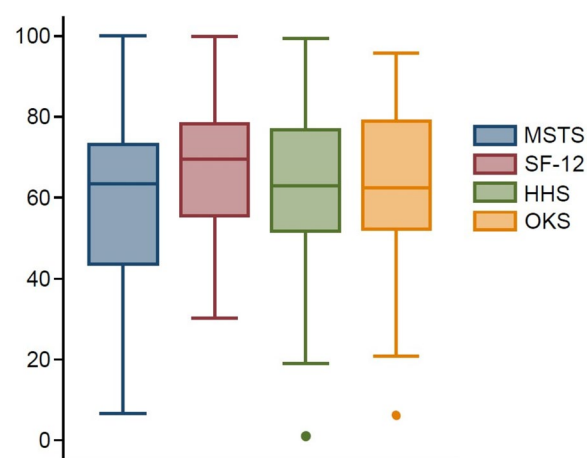
revision without development of deep infection or need for implant revision ($n=10$) and infection treated through suppressive antibiotics therapy without any revision surgery performed ($n=1$). Hip disarticulation was ultimately carried out in two patients (3.1%) at 40 and 42 months follow-up. In total, 60% of patients ($n=39$) with TFR did not require implant revision throughout follow-up. In 43% of patients ($n=28$), no reoperation (also counting all further surgical procedures related to the TFR but not addressing the implant directly) was performed.

Quality of life and clinical performance: PROMs, ROM, and Gait

Median MSTS score was 19 (IQR, 13–22; possible range, 0–30; 59/65 reported), median SF-12 score 39 (IQR, 31–44; possible range, 0–56; 63/65 reported), median HHS 63 (IQR, 51.5–77; possible range, 0–100; 64/65 reported), and median OKS 30 (IQR, 25–38; possible range, 0–48; 63/65 Fig. 2).

The median ROM of the hip and knee joints (i.e., extension-to-flexion) were, respectively, 80° (IQR, 70–97.5°; 64/65 reported) and 70° (IQR, 40–90°; 63/65 reported).

Gait videos were available in 24 patients (36.9%). The median total EVGS of the operated side was 8.5 (IQR,

**Fig. 2** Box plots showing median levels of MSTS, SF-12, HHS, and OKS for the entire cohort

6–13), while on the contralateral side, the median score was 4 (IQR, 2–5). The operated limbs' scores showed mild deviations in 2 patients, moderate deviations in 12, and marked deviations in 10. Severe pathology was observed in none of the patients. Supports (crutches, walkers) were needed by 14/24 patients (58.3%).

On the operated side, an unphysiological trunk shift laterally (excessive or reduced lateral shift toward the stance leg) was recorded in most patients (17/24, 70.8%), being markedly deviated in 3 and moderately in 14. This lateral trunk lean was also reported when bearing on the contralateral side in 14 patients (58.3%, marked in 2, moderate in 12). Furthermore, a forward or backward lean of the trunk (which physiologically should be erect during stance and swing) was observed in ten patients (41.7%; two marked, eight moderate). All patients (24/24; 100%) had deviations of the hip on the operated side, and 23/24 (95.8%) on the contralateral side. The most common unphysiological aspect on the operated as well as contralateral limb was the pelvic obliquity at mid-stance (physiologically $\leq 5^\circ$). In 20/24 patients (83.3%) the EVGS-knee-items on the operated leg differed from norm, with the most severe pathology registered for the peak knee flexion in swing phase. On the contralateral side, the knee-related scores were physiological (0 points) in 21/24 (87.5%) patients. The seven foot and ankle EVGS items showed completely physiological gait in only one patient (4.2%) on the operated side, and in more than half of patients contralaterally ($n = 13$, 54.2%). Initial contact in stance was physiological (heel) in 12, and pathological (flatfoot or toes) in 12 (each 50.0%); foot clearance in swing phase was moderately deviated in 17 (70.8%) and markedly deviated in 2 (8.3%) on the operated side.

Younger age at study-related follow-up significantly correlated with better PROM levels (MSTS, SF-12, HHS, and OKS; Fig. 3; Table 3.). Oncologic TFR indications were significantly associated with better MSTS and OKS levels (Fig. 4). Primary TFR implantations significantly correlated with better MSTS scores.

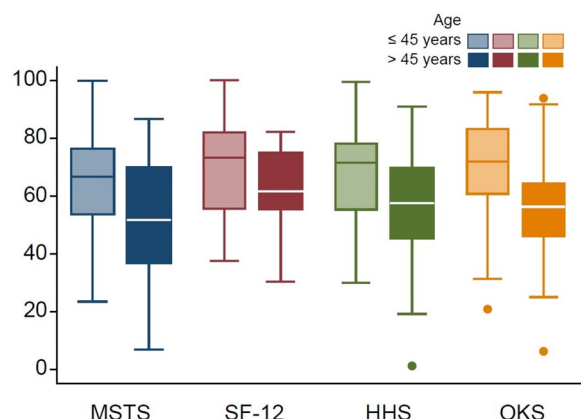


Fig. 3 Box plots showing median percentage levels of MSTS, SF-12, HHS, and OKS separately for patients aged ≤ 45 years and patients aged > 45 years at study-related last follow-up

With the numbers available, no parameter significantly associating with the EVGS levels on the operated or contralateral side was identified.

Discussion

Total femur replacements are seldomly performed limb salvage procedures in orthopaedic oncology and orthopaedic revision surgery, with high proportions of complications and revisions (up to 60%) [1–3]. The at-risk patient population presents high mortality and morbidity (also, but not only, due to the underlying oncological condition) [1–3]. With scarce prior literature regarding functional outcomes, QoL, and gait following TFR, this retrospective multicentric EMSOS study aims to fill those gaps: reporting on function and QoL measures after TFR, presenting results from gait video analysis, and detecting possible associations between demographics and PROM or gait scores.

Median QoL measures scores of 63% (MSTS) and 70% (SF-12), as well as median subjective outcome scores of 63% (OKS) and 63% (HHS), were herein observed. The median ROM of the hip and knee joints, respectively, were 80° and 70° . The gait video analyses, performed in 24 patients, detected a median total EVGS of 8.5 on the operated and 4 on the contralateral side. The operated limb scores were pathological (> 0) in all (24/24) patients. Compensational gait pathology (mild to moderate deviation from norm) on the contralateral side EVGS was detected in 23/24 patients (96%). Better outcome measures (higher scores) significantly correlated with younger age at study-related follow-up (all PROMs), oncologic indications (MSTS and OKS), and primary TFR implantations (MSTS).

Limitations

This study has several limitations. First, data were gathered retrospectively, relying on electronic patient dossiers and documentation, and by a variety of observers owing to the multicentric study design. Although standardized study protocols and instructions were provided, this variability must be considered when interpreting the study's findings. Second, despite all eligible TFR patients being invited to the study-related follow-up at the reference center, only a subset of patients could be seen and included. TFRs are performed at highly specialized hospitals, but these may not be in the vicinity of the patient's place of residence. Owing to the patients' reduced mobility and high morbidity, coming to the specialized center for a study-related follow-up is often not possible or feasible. Therefore, the estimates of activity levels made in this study must be appraised as best-case estimates, given that patients unaccounted for are likely doing worse than those represented here. Furthermore,

Table 3 Pairwise comparisons between binary and continuous variables through the Wilcoxon-rank-sum test

Variable	Subgroups	No. of patients	Median (IQR)	p-Value
MSTS				
Indication	Oncologic versus nononcologic	59	66.7% (53.3–73.3) 43.3% (36.7–53.3)	0.003
Implantation	Primary versus secondary		66.7% (53.3–76.7) 48.3% (36.7–63.3)	0.013
Age at follow-up	≤ 45 years versus > 45 years		66.7% (53.3–76.7) 51.7% (36.7–70.0)	0.032
Major complication	Yes versus no		53.3% (36.7–71.7) 66.7% (56.7–73.3)	0.067
Reoperation	Yes versus no		65.0% (53.3–73.3) 53.3% (36.7–73.3)	0.255
Follow-up time	≤ 28 months versus > 28 months		65.0% (36.7–73.3) 53.3% (46.7–70.0)	0.335
Sex	Male versus female		61.7% (36.7–76.7) 66.7% (36.7–76.7)	0.830
SF-12				
Age at follow-up	≤ 45 years versus > 45 years	63	73.2% (55.4–82.1) 61.6% (55.4–75.0)	0.046
Indication	Oncologic versus nononcologic		71.4% (55.4–78.6) 59.8% (55.4–73.2)	0.142
Implantation	Primary versus secondary		71.4% (53.6–78.6) 60.7% (55.4–75.0)	0.424
Major complication	Yes versus no		66.1% (53.6–75.0) 73.2% (60.7–78.6)	0.158
Reoperation	Yes versus no		69.6% (55.4–78.6) 69.6% (55.4–78.6)	0.706
Follow-up time	≤ 28 months versus > 28 months		75.0% (57.1–82.1) 65.2% (53.6–74.1)	0.135
Sex	Male versus female		68.8% (55.4–78.6) 71.4% (55.4–78.6)	0.938
HHS				
Age at follow-up	≤ 45 years versus > 45 years	64	71.5% (55.0–78.3) 57.5% (45.0–70.0)	0.021
Indication	Oncologic versus nononcologic		70.0% (55.0–78.3) 56.5% (45.0–69.0)	0.051
Implantation	Primary versus secondary		69.5% (55.0–78.3) 60.0% (51.0–73.0)	0.266
Major complication	Yes versus no		62.5% (50.0–75.0) 65.0% (57.0–78.3)	0.382
Reoperation	Yes versus no		60.0% (55.0–76.0) 69.5% (50.0–78.2)	0.760
Follow-up time	≤ 28 months versus > 28 months		60.0% (55.0–73.0) 70.0% (45.0–82.0)	0.432
Sex	Male versus female		65.0% (52.0–76.0) 61.0% (51.0–78.2)	0.973
OKS				
Indication	Oncologic versus nononcologic	63	66.7% (58.3–81.3) 53.1% (43.8–62.5)	0.013
Age at follow-up	≤ 45 years versus > 45 years		71.9% (60.4–83.3) 56.3% (45.8–64.6)	0.004
Implantation	Primary versus secondary		65.6% (57.3–80.2) 58.3% (45.8–77.1)	0.088
Major complication	Yes versus no		62.5% (52.1–77.1) 66.7% (58.3–81.3)	0.234
Reoperation	Yes versus no		62.5% (43.8–77.1) 62.5% (54.2–81.3)	0.457
Follow-up time	≤ 28 months versus > 28 months		62.5% (52.1–77.1) 64.6% (45.8–81.3)	0.720
Sex	Male versus female		64.6% (56.3–79.2) 60.4% (47.9–81.3)	0.314

Table 3. (continued)

Percentage median scores, percentage interquartile range (IQR) scores, and *p*-values are reported. The number of patients column refers to the number of patients for whom the analyzed score was available. Statistically significant results (*p* values) are reported in bold

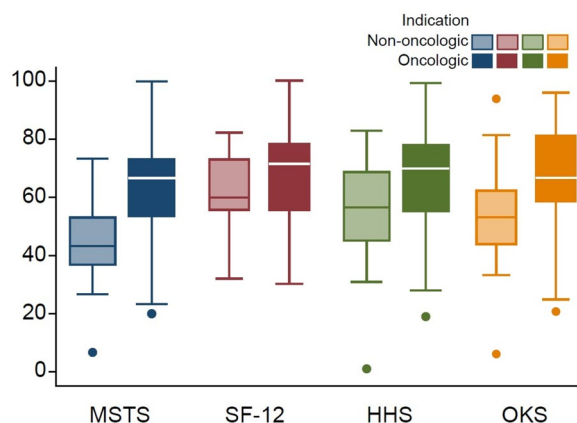


Fig. 4 Box plots showing median percentage levels of MSTS, SF-12, HHS, and OKS separately for patients depending on indication for TFR (nononcologic versus oncologic)

the reduced mobility and high morbidity explain the low proportion of gait videos available. Hence, the gait quality could be analyzed only in a minority of TFR patients, limiting the representativeness of data. Third, owing to the wide range of possible prior surgeries, indications for the TFR, and comorbidities influencing the patients' mobility and function, some cotreatment bias cannot be ruled out. Also, owing to the multicentric study design, post-surgical treatment including postoperative physiotherapy and rehabilitation was not standardized. Finally, the identified associations through multiple univariable Wilcoxon tests must be appraised considering the risk of false-positive findings that this multiplicity carries along. Overall, the results of this study must be analyzed considering these limitations, which cannot be avoided when retrospectively analyzing such complex procedures, in an at-risk population, in a multicentric setting, spanning over decades.

Function and quality of life PROMs

Our results reconfirm prior literature's reports of reduced motion, function, and QoL, with studies including functional and/or QoL assessments after TFR (and generally megaprosthesis reconstructions of the lower limb) being very seldom [2, 4–9]. The chosen PROM scores in the present study refer to the subjective function of the hip (HHS) and knee (OKS) joints, and to general outcome (MSTS) and QoL (SF-12). As previously stated, the results must be considered best-case estimates, given that patients lost to follow-up are likely to do worse than those

represented. Similar MSTS scores were reported in prior studies on TFRs [2, 5]. No comparison or prior published data on the other PROMs or ROM levels are available on TFRs. Overall, these QoL and functional score levels are moderate to good, and comparable to slightly inferior to those reported for other megaprosthesis reconstructions. For instance, mean MSTS levels of 72.8% were reported in 32 proximal femur replacement patients [17]. For distal femur replacements, an excellent outcome based on the MSTS score (i.e., 23–30/30 points) was observed in 46% of patients [18]. Comparable SF-12 levels to those in our TFR cohort were also reported in 63 proximal femur replacement patients [19].

Of note, younger patients' age (at study-related follow-up) significantly correlated with better MSTS, SF-12, HHS, and OKS levels. Generally fewer comorbidities, higher preoperative physical performance levels, as well as the increased rehabilitation potential at younger age account for better PROM scores assessing QoL, general outcomes, and subjective function. Neither having developed a major complication (leading to implant revision) nor undergoing reoperation(s) significantly correlated with worse outcome measures in our TFR cohort. In accordance with this finding, no effect of postoperative complications on sports activity was detected, and no sports activity-related complications were reported when analyzing physical performance after megaprosthesis reconstructions of the lower limb in prior literature [8]. In contrast with our results, patients undergoing additional surgeries for complications were significantly associated with worse MSTS scores compared with those without reoperations in a cohort of 45 children treated through extendable endoprosthetic replacements (including one extendable TFR) [20]. Moreover, oncologic TFR indications were significantly associated with better MSTS and OKS (compared with nononcologic), and primary TFR implantations significantly correlated with better MSTS levels (compared with secondary implantations). These results are intertwined, as primary TFR implantations were performed in most oncologic patients (41/46, 89%), and in none of the nononcologic indications (all secondary implantations). As oncologic TFR implantations are mostly primary, while nononcologic TFRs are per definition secondary or revision implantations, differences reported on one of these two categories necessarily mirror divergencies in the other. Our findings partly confirm prior studies' results. In fact, a systematic review of TFRs implanted in oncologic or nononcologic cases reported significantly better MSTS scores within the oncologic

group [2]. Instead, in another systematic review, no significant differences in the MSTS levels were detected between oncologic and nononcologic subgroups [5].

Gait video analysis

Our study reports the results of a multicentric gait video analysis based on the EVGS of a total of 24 patients with TFR. The EVGS was chosen owing to its widely proven validity [21] and good intra- and interobserver reliability [22]. The numerical values of the EVGS elements correlated well with the measurements obtained from instrumented gait analysis [22]. The gait scores per limb were divided into categories depending on the gait's quality, considering that the minimal clinically important difference for EVGS is 2.4 points [23]. The operated limb scores were pathological in all patients (24/24; moderately deviated in 12/24, markedly in 10/24), with the contralateral limb score differing from norm in almost all (96%, 23/24) patients.

The descriptive analyses of the patients' gaits revealed a wide walk, short steps, with pelvic and trunk tilts. Frequently (in 58.3% of patients), crutches or a walker were needed. These general observations reconfirm reports of prior studies. A recent systematic review found that 70% of patients required walking aids postoperatively, underscoring the ongoing mobility limitations commonly faced after TFR [5]. Other studies analyzing mobility and physical performance after megaprotheses of the lower limb reported strongly reduced mobility levels, with physical performance resembling that of elderly individuals [6], as well as decreased sports activity levels [7–9] and reduced work ability [9]. So far, no gait analysis data has been published for TFR patients, whilst some gait analyses results are available for other megaprotheses (e.g., distal femur replacements). Significantly lower walking speeds and cadence, longer swing, shorter stance phases, shorter steps, and compensatory gait abnormalities contralaterally were found in these studies [10–13]. The very common compensatory gait deviations on the contralateral limb highlighted by our study mirror those reported on other reconstructions [11, 12]. For distal femur replacements, reduced gait quality in contralateral legs were found in 92.3% of patients [12]. More specifically, in our cohort, unphysiological trunk shifts (lateral and sagittal) and deviations of pelvis-related items were found very commonly. These can be attributed to leg length differences, gluteal insufficiency, muscle loss, and/or soft tissue resections at the proximal thigh associated with TFR. With the limited numbers we had, no variable or potential risk factor was identified as significantly associated with worse gait scores. All the recurrent gait pathologies, including the contralateral compensations, need to be

considered and addressed carefully in physiotherapeutic postoperative rehabilitation.

Conclusions

Better functional and QoL outcomes, in terms of PROM scores, were detected after TFR in younger patients, with oncologic indications, as well as primary implantations. All outcome measures, motion and gait data herein presented must be appraised as best-case estimates. The gait pathologies observed on the operated limb as well as the compensational gait deviations on the contralateral side should be considered in aftercare, rehabilitation, and counseling of patients with TFR. These results underscore the need for tailored rehabilitation strategies to address compensatory mechanisms, optimize patients' mobility, and enhance long-term outcomes. Consequences for physiotherapy protocols can be expected. However, long-term follow-up studies evaluating the course of objective function over time are warranted.

Abbreviations

TFR	Total femur replacement
IQR	Interquartile range
PROM	Patient-Related Outcome Measure
ROM	Range of motion
MSTS	Musculoskeletal Tumor Society Score
SF-12	12-Item Short-Form Health Survey
HHS	Harris Hip Score
OKS	Oxford Knee Score
EVGS	Edinburgh Visual Gait Score
QoL	Quality of life
Coef.	Correlation coefficient
CI	Confidence interval

Acknowledgements

We thank all patients who participated and allowed their data to be anonymously used for the present study. This work is part of a research project carried out under the Doctoral Program in Medical Science at the Medical University of Graz. We thank all the participating centers and colleagues of the EMSOS TFR Study group for their collaboration in this project: Giuseppe Bianchi (IRCCS Istituto Ortopedico Rizzoli Bologna, University of Bologna), Thomas Hilton (Groote Schuur & Red Cross Hospitals, University of Cape Town), Maciej Jackowiak (Wojewódzki Szpital Zespolony Toruń), Adyby – Adrian Khal (University Hospital of Marseille, Pelican Medcover Hospital of Oradea), Alexander Klein (LMU University Hospital Munich), Minna Laitinen (Helsinki University Hospital), Blaz Mavcic (University Medical Centre Ljubljana), Vania Oliveira (ICBAS University of Porto), Omer Or (Hebrew University Hadassah Medical Centers Jerusalem), Harzem Özgür (Istanbul Faculty of Medicine), Andrea Sambri (IRCCS University Hospital Bologna). Furthermore, we thank the following colleagues who also contributed to the present multicenter study: Serkan Bayram, Aleksandra Górna, Nicola Seoni and Rafał Szczurowski. EMSOS TFR Study Group: Giuseppe Bianchi, MD: Orthopedic Oncology Unit, IRCCS Istituto Ortopedico Rizzoli, Bologna, Italy; Department of Biomedical and Neuromotor Sciences (DIBINEM), Alma Mater Studiorum-University of Bologna, Bologna, Italy; Via Alessandro Codivilla, Bologna, Italy; giuseppe.bianchi@ior.it. Thomas Hilton, MD: Groote Schuur & Red Cross Hospitals, University of Cape Town; Anzio Road Observatory, Cape Town, South Africa; thomas@drthilton.com. Maciej Jackowiak, MD: Department of Orthopaedics and Trauma, Wojewódzki Szpital Zespolony, Świętego Józefa 53-59, Toruń, Poland; m.jackowiak@novamed.torun.pl. Adyby – Adrian Khal, MD: Department of Paediatrics Orthopaedics, University Hospital of Marseille, Rue Saint-Pierre 264, Marseille, France; Pelican Medcover Hospital of Oradea, Street Corneliu COPOSU 2, Oradea, Romania; adyby_khal@yahoo.com. Alexander Klein, MD: Orthopaedic Oncology, Department of Orthopaedics and Trauma Surgery;

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Author contributions

Conceptualization: MV, MS, MB, AL, and MAS. Data ascertainment: MV, MAS, and all EMSOS TFR Study Group members. Data curation: MV, MAS, and MS. Formal analysis and methodology: MAS. Project administration: MV. Supervision: MAS. Validation: MV, MS, AL, and MAS. Visualization: MAS. Writing—original draft: MV, MS, and MAS. Writing—review and editing: all coauthors. Approval of the final manuscript: all coauthors and all EMSOS TFR Study Group members.

Funding

This work received no funding.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests

AL received institutional educational grants by Johnson & Johnson, Implantcast, and Medacta outside of the submitted work. MAS received travel grants by Implantcast, Alphamed Fischer, PharmaMar, and ImplanTec, as well as research grants from the Austrian Orthopaedics Society and the Kulturamt Graz outside of the submitted work. TH received payment for lectures and presentations by Smith & Nephew and Novus Health outside of the submitted work. AK received travel grants by Implantcast outside of the submitted work. ML received travel grants from Kir-Fix outside of the submitted work. HÖ holds a mutual patent ownership for PENTA modular tumor prosthesis and extremity reconstruction system with TIPSAN medical devices company, and is the current head of Turkish Musculoskeletal Tumor Society.

Ethics approval and consent to participate

The current study was approved by the local institutional ethical review board (reference number: 35–245 ex 22/23). Informed consent was obtained by all included patients upon study-related follow-up.

Consent for publication

Not applicable.

Received: 29 January 2026 Accepted: 17 May 2026

Published online: 28 May 2026

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