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ORIGINAL PAPER

The push-through total femoral prosthesis offers a functional alternative to total femoral replacement: a case series

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Abstract
Purpose Oncologic resections or complications of segmental femoral prostheses can result in severe bone loss of the femur for which a total femoral prosthesis (TFP) is required. This study assesses whether the loss of stability and function caused by the loss of muscle attachments can be improved by using a push-through total femoral endoprosthesis (PTTF), because it saves parts of the femur and its muscle attachments.
Methods In this retrospective case series, ten patients aged 25–77 (mean 54) who received a PTTF between 2005 and 2014 were included for baseline, complications and survival analysis with a mean follow-up of 5.3 (1.1–9.6) years. Functional outcome was assessed in six patients using the Musculoskeletal Tumor Society (MSTS) score, WHO performance scale, Toronto Extremity Salvage Score (TESS), SF36, EQ-5D, NRS pain score, fatigue score and satisfaction score.
Results The mean MSTS score was 64% (23–93%). Five patients had a WHO performance scale of 1, one patient of 3. Mean TESS was 69% (13–90%). SF36 was most notably limited by physical functioning (mean 48), vitality (68) and general health (67). NRS score was 1.9, 1.8 and 8.3 for pain, fatigue and satisfaction, respectively. There were four failures: two infections (one resulting in amputation and one in a minor revision) and two mechanical failures (which required one revision to a TFP and one minor revision). Patient survival was 100%, limb survival 90%, and prosthesis survival 80%.
Conclusion The push-through total femoral endoprosthesis allows preservation of muscle attachments and offers a good alternative to total femoral prostheses.

Keywords Push-through · Total femoral prosthesis · Limb salvaging · Functional outcome · Arthroplasty

Introduction

Overall outcome and survival rates of lower limb malignancies have improved rapidly since the 1970s due to improved (neo) adjuvant chemotherapy and limb-salvaging procedures [1–3]. However, the severe femoral bone loss and extensive soft tissue damage that is associated with limb-salvaging surgery and complications of arthroplasty required the development of megaprostheses [3]. The current megaprostheses offer satisfying results, however, complications such as infection or dislocation are common [4–8]. Proximal or distal femoral prostheses outperform total femoral prostheses (TFPs), which is often attributed to the conservation of the muscle insertions at the remaining femoral bone [4, 7, 9]. The integrity of the hip abductors and knee extensors affects the functional result of a TFP; hip dislocations occur more often after the abductor muscles are excised [10]. Attempts to fixate these muscles on the prosthesis have mostly been unsuccessful [9, 11].

The "Durchsteck"—or push-through—total femoral endoprosthesis (PTTF) (Figs. 1, 2, 3, and 4) distinguishes itself from the 'regular' TFP by connecting the knee component to the hip component with an intramedullary metal stem. This allows preservation of any remaining femoral cortex and its muscle attachments (Fig. 2), which should increase

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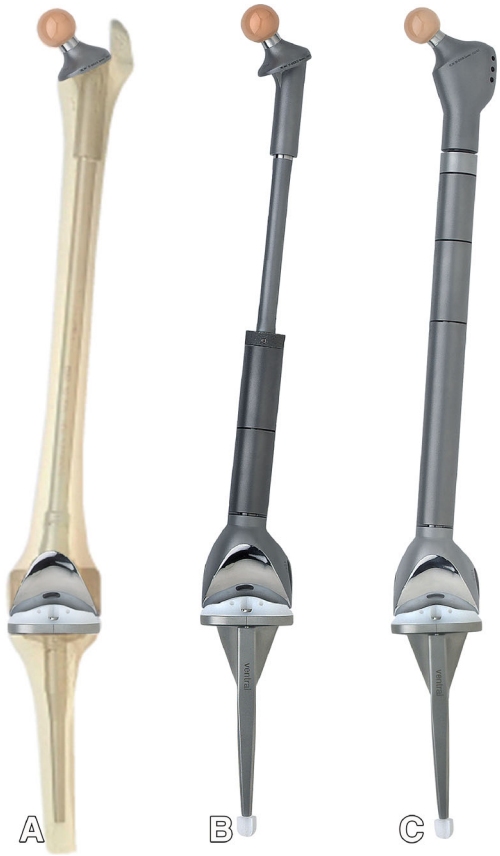

Fig. 1 The concept of the push-through total femoral endoprosthesis and total femoral prosthesis (Megasystem-C, Waldemar Link GmbH & Co. KG). **a** The push-through total femoral prosthesis (PTTF) allows preservation of muscle attachments on any remaining femoral bone. **b** Example of a modular PTTF that preserves the proximal femur. **c** Example of a total femoral prosthesis (TFP). The proximal part of the prosthesis usually offers a way to attach the hip abductors to the prosthesis

stability and motor control, reduce dislocation rate, allow immediate weight bearing, early rehabilitation and enhance functional outcome.

An analysis of the functional and mechanical performance of the concept of the PTTF has, to our knowledge, never been reported. The few reports that mention PTTFs often group them with TFPs, without assessing this specific concept separately [12]. This study reports the results of the PTTF and assesses this concept as a potential alternative to total femur reconstruction.

Materials and methods

Study design

All patients who received a PTTF in two university medical hospitals and one general hospital were included in this retrospective study. All cases that were identified were treated between 2005 and 2014. Patients were excluded if follow-up was ≤one year.

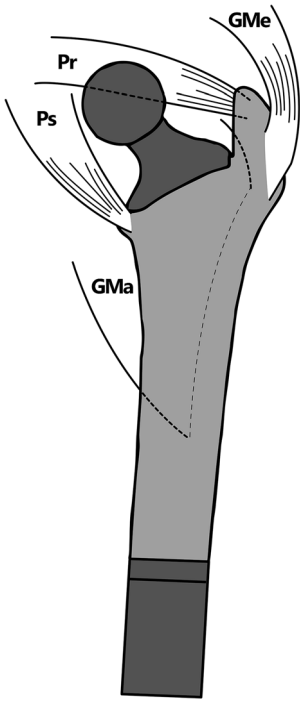

Fig. 2 Advantages of the push-through total femoral prosthesis. This example shows how some of the important hip muscles can be spared in the case that only the most proximal part of the femur is preserved. Only the gluteus medius (GMe), gluteus maximus (GMa), piriformis (Pr), and iliopsoas (Ps) are shown in this example. Others, such as the quadratus femoris, can be spared as well but are not shown in this image. This is not possible when using a total femoral prosthesis

Study procedure

At baseline, patient characteristics, surgical indication (in case of oncology: oncologic diagnosis and the year of the original diagnosis) and patient history were obtained. All patients were asked to fill out the patient reported outcome measures (PROMs) during a follow-up appointment if no recent questionnaire was present in the existing database.

Surgical procedure

The surgical approach was subject to variations due to specific patient history and previous surgeries. A patient specific plan was made, based on measurements on a recent CT scan. The patient was positioned in a lateral decubitus position. The hip was approached via the (postero)lateral approach, which was extended along the femur, dorsal of the vastus lateralis muscle. The knee approach was usually midline or anteromedial. In some cases, two separate incisions were used. After preparation of the hip and acetabular components, the knee and tibial components were prepared and placed in situ. A trial reduction was performed with a trial push-through stem into the socket. When this construction proved to be stable and in the right rotation, the definitive prosthesis was assembled

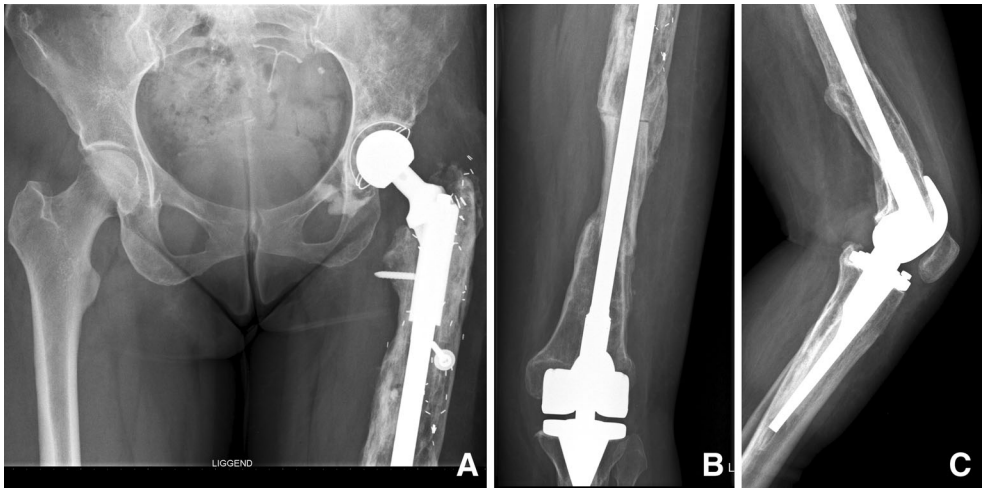

Fig. 3 An example of the push-through prosthesis taken one year post-operatively. **a** Anterior-posterior radiograph of the pelvis, showing the proximal PTTF and Exeter cup. The push-through stem provides stability after several failed osteosynthesis attempts and a vascularised fibula transplant. **b** Anterior-posterior radiograph of the left distal femur and knee. The distal cortex is spared due to the push-through stem. **c** Lateral radiograph of the left knee, showing the rotating hinge knee

and placed. Patients with severe comorbidity were monitored post-operatively in the intensive care unit for 24 hours.

Outcome measures

The primary outcome measure is the widely used lower limb version of the Musculoskeletal Tumor Society (MSTS) score, which measures functional outcome from the surgeon's point of view; it scores pain, function, emotional acceptance, use of supports, ability to walk and gait on a scale of 0-100% [13].

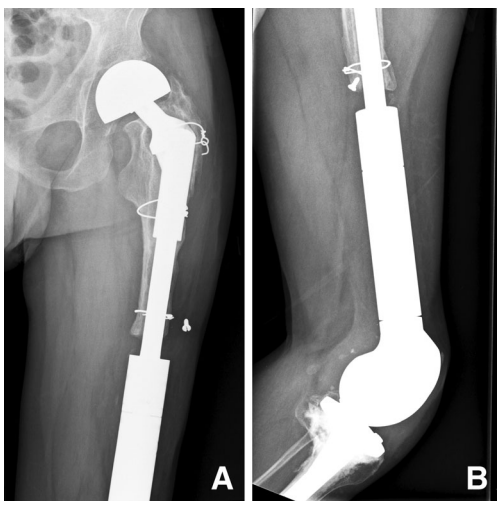

Fig. 4 An example of the push-through prosthesis taken five years postoperatively. **a** Anterior-posterior radiograph of the left hip and proximal femur. Note how the proximal muscle attachments are spared. Extra cerclage wires are used to improve post-operative fixation of the remaining bone. The Link Variocup is used in this case (hemiarthroplasty). **b** Lateral radiograph of the rotating-hinge construction of the PTTF. The distal femur has been replaced with a modular push-through construction

Secondary outcome measures (PROMS) feature the numeric rating scale (NRS-11) pain score, NRS fatigue score, NRS satisfaction score, WHO performance status, Toronto Extremity Salvage Score (TESS), EQ-5D-3 L and SF36 health survey. The NRS-11 requires patients to rate their level of pain, fatigue, and satisfaction on a scale from 0 to 10 [14]. The WHO performance status quantifies the patient's ability to function in daily life on a scale from 0 (no impairments) to 5 (death) [15]. The lower limb version of the TESS evaluates physical function and daily activities in patients who suffer from musculoskeletal tumors, on a scale of 0–100% [16]. The EQ-5D-3L questionnaire (Dutch language, version 1.0) is a standardized health assessment instrument that scores mobility, self-care, usual activities, pain/discomfort and anxiety/depression [17]. The Dutch version of the SF36 Health Survey is a validated quality of life questionnaire [18].

Other outcome variables

Peri-operative variables include: duration of surgery, length of stay (LOS), American Society of Anaesthesiologists (ASA) score, and complications (infection, bleeding, transfusion required, thromboembolic events and dislocation).

Patient variables include patient reports, physical examination and range of motion (ROM), survival (and cause of death) and prosthesis failure. Prosthesis failure is defined according to the Henderson classification as: complete revision of endoprosthesis, unplanned revision of a failed part of the prosthesis, fixation of a periprosthetic fracture, soft-tissue reconstruction to improve stability or complete removal of the endoprosthesis without revision or amputation [19]. It is subdivided into type: (1) soft-tissue failure, (2) aseptic loosening, (3) structural failure, (4) infection and (5) tumor

progression. Complications and peri-operative data up to the removal of the prosthesis were included in the analysis.

Statistical analysis

Descriptive statistics were used to describe outcome measures. The choice was made to use means and ranges for parametric variables, despite the small sample size, because means are used in virtually all comparative literature. Additionally, medians are reported in the outcome table, to provide a better understanding of the data. Medians with ranges were used for non-parametric data. All data was processed using SPSS version 22.

Ethics

The medical ethical committee (METc UMCG) declared that ethical testing for this study was not necessary, in accordance with Dutch law. For this type of study formal consent is not required. All actions related to this research 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.

Results

Details on inclusion and exclusion are reported in Fig. 5. Baseline characteristics are reported in Table 1. Mean age at surgery was 54 (range 25–77). In seven cases the underlying pathology was oncologic in nature (Table 1).

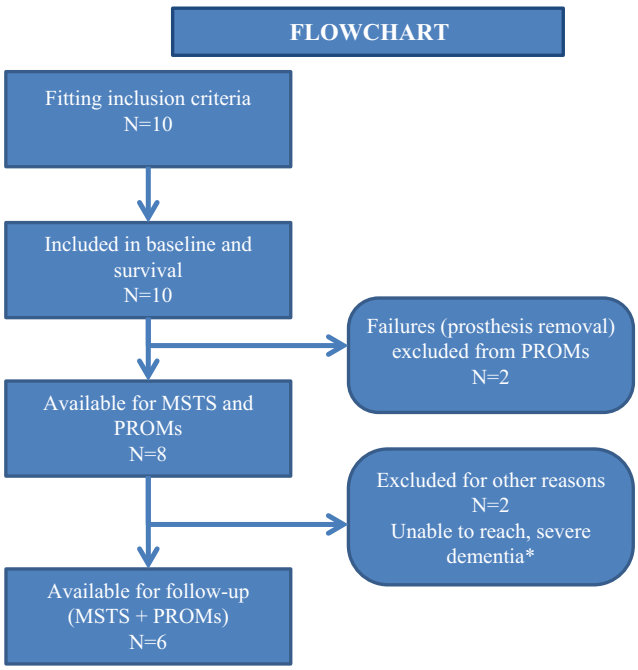

Fig. 5 Study flowchart of inclusion and exclusions. *One patient suffered from severe dementia and therefore was not able to fill out the PROMs

A modular Megasystem-C (Waldemar Link GmbH & Co., Hamburg, Germany) endoprosthesis was used in eight cases and a custom made Restoration Modular and MRH/GMRS (Stryker, USA) endoprosthesis was used in two cases. All prostheses featured a rotating-hinge knee. The proximal femur was replaced with the Variocup (Waldemar Link GmbH & Co., Hamburg, Germany) (hemiarthroplasty) in five cases. The other five cases received a total hip replacement with a 'dual mobility' Avantage (Biomet, Warsaw, Indiana, USA) cup (3 cases), an Exeter High-wall cup (Stryker, USA) (1 case) and an Exeter Rimfit cup (Stryker, USA) (1 case). Mean follow-up was 5.3 (1.1–9.6) years.

Primary and secondary outcome

Primary and secondary outcomes are reported in Table 2. Surgery required 6:33 (4:05–8:46) hours on average. Mean length of stay was 14 (5–41) days. Mean hip flexion was 87° (45–110°). Mean knee flexion was 88° (40–110°). During follow-up, there were no radiographic signs of prosthesis loosening in any of the cases.

Oncologic outcome

All seven oncologic patients were continuously disease-free (CDF) at a mean follow-up of 6.3 (1.1–9.6) years.

Complications

There were two infections. Both are described in detail under 'Patient and prosthesis survival'. Furthermore, one case of post-operative bleeding required surgical drainage of a large haematoma. Transfusion was required in seven cases due to peroperative blood loss, and in one case to treat pre-existent anaemia. No thromboembolic events or hip dislocation occurred.

Patient and prosthesis survival

Patient survival was 100% at a mean follow-up of 5.3 (1.1–9.6) years. Four prostheses (40%) failed in this series: one of which required amputation, one required major revision to a standard TFP, and two required a minor revision. Mean time to failure was 4.4 (1–9) years.

The first failure was due to infection. A female patient with severe rheumatoid arthritis underwent a two-stage revision of her DFP due to loosening, a suspected low-grade infection with *Staphylococcus aureus* and a coincidentally-discovered chondrosarcoma in the femur. Cultures of tissue samples obtained during implantation of the custom-made Stryker Restoration Modular PTTF

Table 1 Baseline characteristics

Case	Sex	Age (years)	Indication for PTTF	Primary pathology	Previous surgery	Original diagnosis (year)	ASA	LoF (years)	Prosthesis	Hip
1	F	52	Infected DFP	RA+CS	2xTHP, DFP, Sp	2005	3	9.1	Stryker	Striker Exeter High-wall acetabular cup
2	M	35	Broken DFP	OS	Or, 2xDFP, collum#	1981	2	8.5	Link	Variocup hemiarthroplasty
3	F	47	Nonunion/failing Osy	FS	2xOr, RT, femur#, Osy, VFT, tibia#, THP, femur#, Osy	1988	2	1.1	Link	Stryker Exeter rimfit
4	M	45	Broken DFP	OS	Or, 2xDFP	1987	3	3.0	Link	Biomet Avantage cup
5	F	67	PPF/loosening TKP	RA	THP+ Mr, TKP, femur#	–	3	2.7	Stryker	Biomet Avantage cup
6	F	74	Asept loosening DFP	GCT	Or, DFP, 2xMr	1988	3	3.4	Link	Variocup hemiarthroplasty
7	F	77	Asept loosening THP	OP/OA	2xTHP, Gs	–	2	3.3	Link	Biomet Avantage cup
8	F	25	Nonunion Osy	OS	Or, 4xOsy	2001	3	9.6	Link	Variocup hemiarthroplasty
9	F	63	Asept loosening DFP	OS	Or, DFP	2005	2	9.1	Link	Variocup hemiarthroplasty
10	F	57	Vancouver X PPF TKP	OA	TKP, femur#	–	2	3.2	Link	Variocup hemiarthroplasty

fracture, *F* female, *M* male, *CS* chondrosarcoma, *DFP* distal femoral prosthesis, *GCT* giant cell tumor, *Gs* Girdlestone, *LoF* length of follow-up, *Mr* minor revision, *Op* osteoporosis, *Or* oncological resection, *OS* osteosarcoma, *Osy* osteosynthesis, *PPF* periprosthetic fracture, *PTTF* push-through total femoral prosthesis, *RA* rheumatoid arthritis, *RT* radio therapy, *Sp* spacer, *THP* total hip prosthesis, *TKP* total knee prosthesis, *VFT* vascularized fibula transplant

Table 2 Outcome measures

Outcome measure	Mean	Median	Range
MSTS-score (%)	64	68	23–93
NRS-pain	1.9	0	0–5
NRS-fatigue	1.8	0	0–6
NRS-satisfaction	8.3	8.3	6–10
WHO (frequency of occurring)			1(5)–3(1)
TESS (%)	69	79	13–90
EQ-5D	0.774	0.791	0.434–1
SF36			
SF36-physical functioning	48	53	0–80
SF36-social functioning	69	75	0–100
SF36-role limit physical	50	50	0–100
SF36-role limit emotional	72	83	0–100
SF36-mental health	75	72	64–88
SF36-vitality	68	70	45–90
SF36-pain	72	79	10–100
SF36-general health	67	65	60–80
SF36-health change	29	25	0–50

MSTS Musculoskeletal Tumor Society score, *NRS* numeric rating scale, *WHO* World Health Organisation performance scale, *TESS* Toronto Extremity Salvage Score, *EQ-5D-3L* EuroQol health-related quality of life survey, *SF36* Short Form 36 health survey. Both the mean and median are listed for variables that usually fit a normal distribution because due to the small sample size, the mean is sensitive for outliers.

were negative. The low-grade periprosthetic infection with *Pseudomonas aeruginosa*, which arose after three years, resulted in surgical debridement and hip disarticulation after five years of suppressive antibiotics.

The second failure was due to the material. The connection between the MRH knee prosthesis and the custom-made Stryker Restoration Modular femoral stem broke after almost three years, during walking. It was revised to a Stryker GMRS total femoral prosthesis.

The third failure was due to a spontaneous infection, five years after receiving the Link Megasystem-C PTTF. The periprosthetic infection was treated with i.v. antibiotics, surgical debridement of the wound and local gentamicin beads. Eventually, all polyethylene parts of the PTTF were replaced and all metal parts were cleaned and re-implanted. Persistent wound problems required a gastrocnemius flap and skin transplant. The patient is now infection free and doing well, three years after finishing the antibiotic treatment.

The fourth failure was due to persistent pain after receiving the Link Megasystem-C PTTF. It was attributed to unsuccessful adherence of the proximal femoral bone to the PTTF, an internal rotation contracture and insufficient anteversion. It was regarded as a structural failure. The anteversion angle was corrected and the proximal femoral bone was cemented onto the prosthesis during a minor revision one year after initial implantation.

Discussion

A push-through total femoral endoprosthesis saves part of the bone and its muscle attachments and most likely preserves its stability and function better than a TFP. A retrospective analysis was performed to assess the outcome of the PTTF. All patients had a long medical history, severe comorbidity and extensive previous surgeries. All patients survived, but the complication rate was substantial. Functional outcome varied from severely impaired to virtually no impairment, however, almost all patients had relevant disabilities. Emotional functioning, perceived health and overall quality of life were less impacted and most patients had little to no pain. Satisfaction with the result of this procedure was very high. There were no hip dislocations.

Mean MSTS score in this study was 64%, which is comparable to mean MSTS scores after primary TFPs (50–73%) [4, 8, 20]. Secondary TFPs might result in lower MSTS scores than primary TFPs (60% versus 73%) [10]. MSTS scores were positively influenced by the lack of use of pain medication; nevertheless, functional impairment and gait decreased the scores. Individual scores showed great variability (23–93%), similar to TFP outcome [8, 20]. A similar spread is seen in the TESS scores (13–90%). Mean TESS scores after TFP range from 47% to 69% in the literature, with equally large inter-patient variability [7, 21]. A mean TESS score of 69% after PTTF is relatively high.

All patients have functional impairments to some degree after total femoral prostheses; five patients had a WHO performance scale of 1 (only limited in heavy exercise) and had an EQ5D index higher than 0.7. One patient had a WHO performance scale of 3 (limited self-care and >50% of the day in bed) and a lower EQ5D score (0.434). 'Usual activities' and 'mobility' impacted the EQ5D index to the greatest extent, while 'self-care', 'anxiety/depression' and 'pain/discomfort' played a smaller role. The low levels of pain are also seen in the NRS pain scores and the SF36 pain sub-scores. Furthermore, four patients experienced no lasting fatigue after the surgery. Two patients experienced fatigue but were very satisfied with their outcome. Many patients mentioned their gratitude for the attempts to spare the leg—as well as the success achieved—and took the alternative option (amputation) into account in their satisfaction scores. Satisfaction scores are surprisingly high despite the functional impairment. The SF36 shows impaired physical functioning (mean 48) and clear limitations (mean 50) due to impaired function. General health perception (mean 67) and perceived vitality (mean 68) show similar scores.

Range of motion plays an important role in the physical functioning of the limb. Mean hip flexion of 87° and knee flexion of 88° after PTTF is higher than after TFP: knee flexion between 60° and 73° (range 0–120°) and hip flexion of 61° has been reported [4, 22]. The theoretical advantages of preserved muscle attachments of the PTTF could explain this; nevertheless, more and other types of studies are necessary to evaluate this.

Complications

In general, complications were comparable to the series by Clement et al. [5], who reported 19 cases of TFP after periprosthetic fractures [5].

Our infection rate (20%) is similar to the reported 10–22% infections after TFP [4–6, 8]. One patient had a previous infection of her DFP, however, this is not a definite contraindication [10].

Hip dislocations occur often after TFP (5.3–23%), though none occurred in our study [5–8, 10]. Our small sample size could be a factor; however, other factors might explain this. Excision of the hip abductor muscles increases dislocation rates of TFPs, something that is averted in the PTTF [7, 10]. Furthermore, all PTTFs were used as secondary limb-salvaging treatment, which is linked to lower dislocation rates in TFPs compared to primary limb salvaging TFPs (9% versus 23%) [10]. Additionally, a dual-mobility Variocup and the Avantage cup were used in most hemiarthroplasties and THPs respectively, which is known to reduce dislocation rates in both primary and revision THAs and hemiarthroplasties [23]. Other studies are necessary to assess these factors.

Aseptic loosening often complicates DFPs, however, implementation of rotating hinge prostheses instead of fixed-hinge prostheses has reduced this significantly [24]. In this study only rotating hinge prostheses were used.

Failures

Failure rate in this study is high (40%), although this might be partly influenced by our broad definition of failure. Sewell et al. reported five-year TFP survival of 100% considering removal as the endpoint, which dropped to 56% with re-operation as endpoint [10]. Our study showed 80% prosthesis survival and 90% limb-survival, which is very satisfying given the type of conditions treated. There were too few patients in our study to draw valid conclusions about the differences between the Link and Stryker techniques. However, a modular design has the advantage that it allows the surgeon to adjust to factors that could not have been foreseen during pre-operative planning.

Patient analysis

It is relevant to note that the lowest functioning patient was impaired by comorbidity (myocardial infarction, rheumatoid arthritis, depression) to a far greater extent than by the outcome of the PTTF, which means her scores might not accurately reflect PTTF outcome. The patient with the worst ROM (hip flexion 45°, knee flexion 40°) previously underwent resection of the knee extensors and partial reconstruction by transposition of the biceps femoris muscle during primary oncologic resection and

patellar resection during revision DFP surgery. All other patients had a knee and hip flexion of more than 90° in our study, which is remarkably good.

The two highest functioning patients both were relatively young, had relatively mild comorbidity and fewer previous surgical procedures (i.e. less soft tissue damage) than most other patients. One patient has a job in the food service industry that requires mostly standing and walking for eight hours a day without problems.

The result of any megaprosthesis will probably improve when patients have had fewer previous surgery; nevertheless, the push-through prosthesis might have more to gain than the TFP because it preserves muscle function while providing the same structural integrity to the femur (Fig. 2). The analysis seems to suggest that the PTTF might be suited for patients with limited soft-tissue damage and sufficient femoral bone stock, while patients with severe soft-tissue damage (i.e. resection of the extensor apparatus) and comorbidity reap none of the benefits and might be better off with a TFP. However, larger studies with longer follow-up will provide more evidence.

Oncologic outcome in the present patients was good and patient survival was 100%. Studies on TFPs often report patient survival rates as low as 32–35%, two to five years after primary tumor resection and limb-salvaging with a TFP [10, 20]. Recurrent disease occurs less often after secondary limb-salvaging surgery [10]. All seven oncologic patients received a PTTF as a secondary treatment because they survived long enough to develop complications of their primary surgery. This inherently selects patients with favourable oncologic outcome.

This patient selection bias (both PTTFs and TFPs were used in the study period) is one of the limitations of this study. Furthermore, the sample size is small because this prosthesis is rarely used. However, all patients who received a PTTF between 2005 and 2014 were included, thus reducing the sampling bias for PTTF patients. Moreover, there is no control group with which to compare the findings. Due to the nature of the prosthesis as a 'last option' for limb-salvaging there is great heterogeneity among the patients. The length of the follow-up varies, making it difficult to note time-dependent changes in the outcome measures. In spite of these restrictions, this is the first study to report specifically on the push-through prosthesis.

In summary, patient satisfaction was very high, despite that functional outcome ranges from severely handicapped to near-normal functioning. Complication rate was within the ranges that are reported in the literature. However, no dislocations occurred. Only one complication resulted in hip disarticulation. The modular PTTF offers the surgeon a good alternative to TFP due to its highly patient-specific approach, preservation of muscle attachments and good functional outcome.

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Compliance with ethical standards

Conflict of interest The corresponding author (Gorter) has received partial support for travel and accommodation for the NOF Congress from Link GmbH & Co. KG, in accordance with the 'Code of Conduct Medical Devices'.

All other authors declare that they have no competing interests.

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