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Original article

Does migration of osseointegrated implants for transfemoral amputees predict later revision? A prospective 2-year radiostereometric analysis with 5-years clinical follow-up

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ABSTRACT

Background: The osseointegrated (OI) prosthesis is a treatment option for transfemoral amputees with a short residual femur and/or difficulties caused by using the prosthetic socket. Implant removal due to aseptic or septic loosening is not uncommon, but the association between implant migration patterns and the need for removal has not previously been studied. We conducted a prospective model-based radiostereometric analysis study to investigate: if the OI implant migration pattern 1) differs between later removed implants and non-removed implants, (2) predicts later implant removal, and (3) if the precision of the method is acceptable.
Hypothesis: Model-based radiostereometric analysis of the OI implant migration pattern can be used to predict later OI implant removal.
Material and methods: A prospective cohort of 17 consecutive transfemoral amputees suitable for surgery (11 males), mean age 50 (range 32-66) were treated with an OI implant (Integrum AB, Sweden). Post-operative stereoradiographs of the OI implant were obtained during 24-month follow-up. X, Y, and Z translations and total translations were evaluated using CAD-implant models. Implant survival was followed for up to 60 months.
Results: Six total implant removals (fixture and abutment) and four partial removals (abutment) were conducted (10/17 (59%)), and one patient did not use the OI implant. The removed implants group migrated a mean (± standard deviation) 0.55mm ± 0.75 mm (p = 0.009) and the non-removed implants group migrated 0.31mm ± 0.51 mm (p = 0.22) in total translations from 3 months to last follow-up. Odds ratio for implant removal was 22.5 (95% CI: 1.6 to 314 (p = 0.021)) if the OI implants migrated distally.
Conclusion: Later removed OI implants migrated from 3 months to last follow-up and more than the non-removed OI implants. Distal implant migration greatly increased the odds of implant removal. Ten out of 17 OI implants were removed within 5 years of follow-up. We advise to use OI implants with caution and close follow-up in consideration of the risk of complications.
Level of Evidence: IV, Prospective study.

1. Introduction

A lower limb amputation is a life-changing event resulting in changes in the body image, physical function and quality of life [1–3]. Approximately 90% are amputated due to vascular diseases and 10% are amputated due to causes such as trauma, tumor, and infection [3]. Patients subjected to transfemoral amputation due to non-vascular diseases, who use a typical socket prosthesis, report problems leading to a reduced quality of life because of heat/sweating in the prosthetic socket, skin problems, inability to walk in uneven terrain, inability to walk quickly, and pain [3]. Osseointegration (OI) implant surgery is a treatment option for patients with a transfemoral amputation caused by non-vascular diseases, which provides a bone-anchored attachment for the external prosthetic leg, thereby alleviating problems associated

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with the prosthetic socket. After rehabilitation patients with an OI implant display improved hip range of motion, better sitting comfort, increased prosthetic use, improved mobility, and improved quality of life [4–8]. The reconstruction of amputated limbs with surgery has mainly been performed by use of three types of femoral osseointegrated implants [9–11]: The OI implant (Integrum AB, Sweden) is made from pure titanium with a threaded uncoated surface and requires a two-stage surgical procedure with a 6-month healing period to acquire sufficient osseointegration [9]. The other implants are longer than the Integrum OI implant. The Integral Leg Prosthesis (ILP) (ESKA Orthodynamics GmbH, Germany) is made from cobalt-chrome-molybdenum with a coated macro-porous surface, and the Osseointegrated Prosthetic Limb (OPL; Permedica s.p.a, Italy) is made from a titanium alloy with a plasma sprayed rough titanium coating. Both implants are inserted using a two-stage surgical procedure with a two-month healing period [10], but recently a one-stage procedure with early implant loading has been described [11].

Implant removals and infections remain a recurring challenge with femoral osseointegrated implants. From 1990 to 2008, the Swedish Osseointegration Team reported Integrum OI implant removal in 20 out of 100 patients. Later, 51 patients (55 implants) were enrolled in the prospective "Osseointegrated prostheses for the Rehabilitation of Amputees" (OPRA) cohort [12–14]. Four implants were removed (1 septic and 3 aseptic) in the OPRA cohort, and they reported a cumulative implant survival rate at two years of 92% [12]. The most common complications in the cohort were superficial infections occurring 41 times in 28 patients [12]. The United Kingdom Osseointegration Team removed two out of eleven Integrum OI implants one year after primary surgery, and five out of 18 OI implants 11 years after primary surgery. [5,15] Further, they registered 11 superficial infections. The German Osseointegration Team reports 8 out of 86 (9.3%) implant (ILP) removals from 2003-2014, 5 infections, 2 aseptic loosening, and 1 implant failure [16]. A two-center study from the Netherlands and Australian Osseointegration Teams reports 3 out of 86 (3.5%) implant (ILP and OPL) removals from 2009-2013 [17]. The most common complication for the OI, ILP and OPL implants are superficial infections of which most can be resolved with oral antibiotics, but a substantial number of patients require intravenous (IV) antibiotics or surgical debridement [12,17,18]. Besides reducing the number of infections, it is imperative for implant survival to acquire a successful early osseointegration. Key to this is limited implant micromotion (a stable fixation) and intimate implant-bone contact [19]. Radiostereometric analysis (RSA) is currently the best available method to assess implant fixation with respect to surrounding bone [20], and implant migration at an early stage (until 2 years) has proven useful for predicting aseptic loosening in knee and hip arthroplasty [21,22]. The high accuracy and precision of RSA [23,24] makes investigations possible with a small study population. Given the predictive power of RSA to detect early implant loosening it has been recommended to implement RSA as an early tool in stepwise introductions of new implants on the market [25]. Currently only one marker-based RSA study has investigated the migration of Integrum OI implants. It was conducted on the OPRA cohort and generally a stable fixation was found at 2-years follow-up [13]; however, the migration pattern of the loose implants was not described. No studies concerning the migration pattern of the ILP and OPL implant currently exists. It is important to know when and why implants for transfemoral amputees lose bone fixation in order to intervene towards improvement of implant survival.

In this study transfemoral amputated patients treated with Integrum OI implants were prospectively examined using model-based RSA with 24-month follow-up and implant survival was followed for 5 years. Based on the OI implant migration pattern we investigated:

- the difference between later removed implants and non-removed implants;
- the prediction of later implant removal;
- the precision of the method.

We hypothesized that the migration pattern of OI implants at two-years could be used to predict later OI implant removal.

2. Material and methods

2.1. Patients

A prospective observational cohort of 17 consecutive patients was operated between 2010 and 2013 at Aarhus University Hospital, Department of orthopedic surgery. Implant fixation was investigated with model-based RSA and imaging was conducted 1, 3, 6, 12, 18 and 24 months after stage 2 surgery. The OI implant position at 1-month follow-up was used as a reference for all migration analyses. Patients were followed for up to 60 months or until partial/total implant removal. According to Danish law, formal approval from the Regional Ethical Committee was not required as all examinations were performed according to an established quality assurance protocol (inquiry number 135/2016). Data were handled according to the regulations of the Danish Data Protection Agency (approval of 2012-28-005).

The cohort consisted of 11 males, 6 females and the mean age was 50 years (range 32–66). The patients had transfemoral amputation at mean 11.75 (range 0 to 39) years previously due to trauma ($n = 7$), tumor ($n = 4$), infection ($n = 2$), thrombosis ($n = 1$) or other causes ($n = 4$). The patients were assessed for eligibility by two senior surgeons. The surgical criteria were healthy transfemoral amputated patients, aged 18–70 years, with body mass index (BMI) < 30, and a bone structure suitable for OI implant surgery. Exclusion criteria were diabetes, smoking, treatment with bisphosphonates, nonsteroidal anti-inflammatory drugs or cytostatic medicine, active cancer, kidney or hepatic insufficiency, dementia, pregnancy, body weight > 100 kg and a transfemoral amputation caused by atherosclerosis.

2.2. Surgical treatment and aftercare

The OI implant system comprised an intraosseous threaded titanium fixture (Integrum AB, Sweden) and a percutaneous abutment (Integrum AB, Sweden) implanted during a two-stage surgical procedure (Fig. 1). At stage 1 (S1), the fixture was inserted into the residual femur and allowed to osseointegrate for 6 months before stage 2 operation. Prophylactic IV dicloxacillin 2 g was administered preoperatively and three times the first postoperative day. At stage 2 (S2), the percutaneous abutment was connected to the fixture making it possible to attach an external prosthesis. IV dicloxacillin 2 g was administered prior to surgery and 3 times/day the next 10 days postoperatively. After S2 surgery, the patients followed a standardized 6-months rehabilitation programme. This included hip range of motion exercise the first 6 weeks followed by weight bearing starting at 20 kg and increased by 10 kg/week the following 6 weeks. After 12 weeks, the patient gradually increased load on the OI implant until full weight bearing was possible (up to a year after S1 surgery) [4].

If a periprosthetic infection was suspected conventional radiographs and positron emission tomography-computed tomography (PET-CT) scans were performed before revision or implant extraction in order to localise the infection site. The surgical revision was performed in general anaesthesia and periprosthetic infection was verified by positive isolation of microorganisms taken from bone marrow samples, cortical bone- and/or deep soft tissue specimens adjacent to the fixture. After implant removal relevant IV antimicrobial treatment was administered for 2 weeks followed by >4 weeks of targeted oral antimicrobial treatment.

2.3. Radiostereometric setup and analysis

Until 2014 all stereoradiographs were obtained using a standard CR RSA setup [26] consisting of two-ceiling fixed, synchronized roentgen tubes (Acro-Ceil/Medira; Santax Medico; Denmark) both positioned at a 20° angle with the vertical plane, and an unfocussed uniplanar carbon calibration box (Box 24; Medis Specials, Leiden, the Netherlands) (Fig. 2). All stereoradiographs were digitized images (Fuji CR (ST-VI IP), 200 μm pixels pitch). In 2014, the radiography equipment was replaced with an automated DR RSA system (AdoraRSA; NRT, Denmark) with ceiling fixed and synchronized roentgen tubes (Varian Medical Systems, USA) and direct digital receptors (Canon CXDI-70 C, 125 μm pixel pitch). We continued using the same RSA setup (tube position, patient position and calibration box).

During S1 surgery, 6–10 tantalum beads (Ø 1.0 mm) were inserted into the femoral cortical bone using a bead gun (Wennbergs Finmek AB, Sweden) (Fig. 2). CAD models of the inserted fixtures were provided by the manufacturer (Integrum AB, Sweden) and implemented in the model-based RSA software by the software provider (RSAcore, Leiden, The Netherlands). The final implant-models were created with 10,000 triangles. Implant migration along the Y-axis in proximal direction (subsidence) was defined as positive motion and the distal direction as negative motion.

The cut-off for stable markers was 0.35 mm (rigid body error) [26]. The mean rigid body error was 0.14 (range 0.024 to 0.35) and sixteen patients had ≥ 3 stable bone markers. Six patients had a condition number (CN) > 120, and the mean CN was 138.4 (range 37 to 406). Analysis was performed using model-based RSA 4.0 (RSAcore, Leiden, The Netherlands) software by one observer (RH).

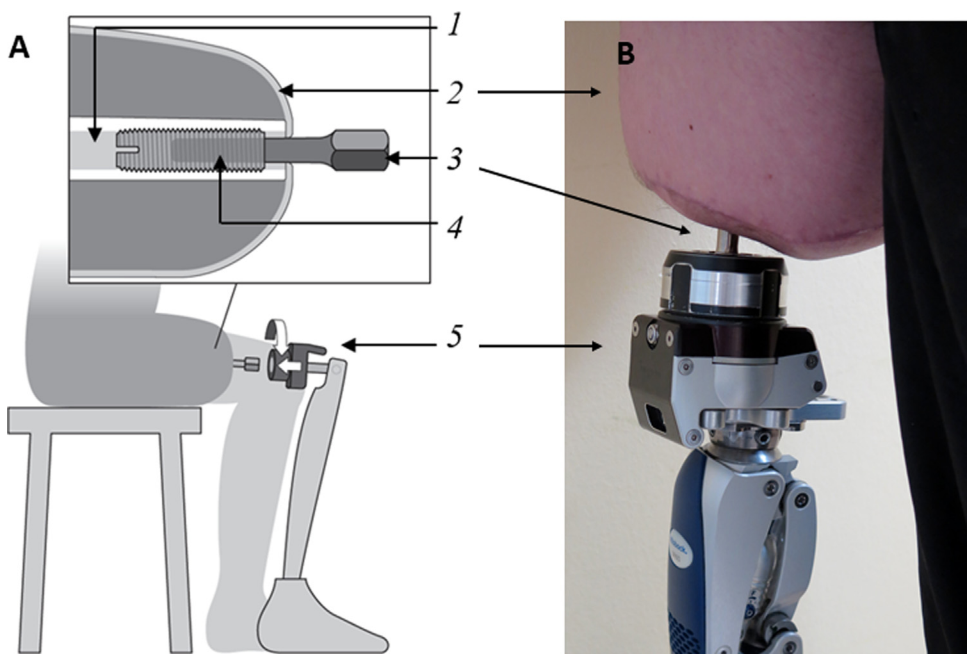

Fig. 1. The OI implant system. (A) Illustration. (B) Patient with the external leg connected to the abutment. (1) Femur bone. (2) Soft tissue. (3) Percutaneous abutment. (4) Fixture. (5) A snap-lock connects the prosthetic leg to the abutment.

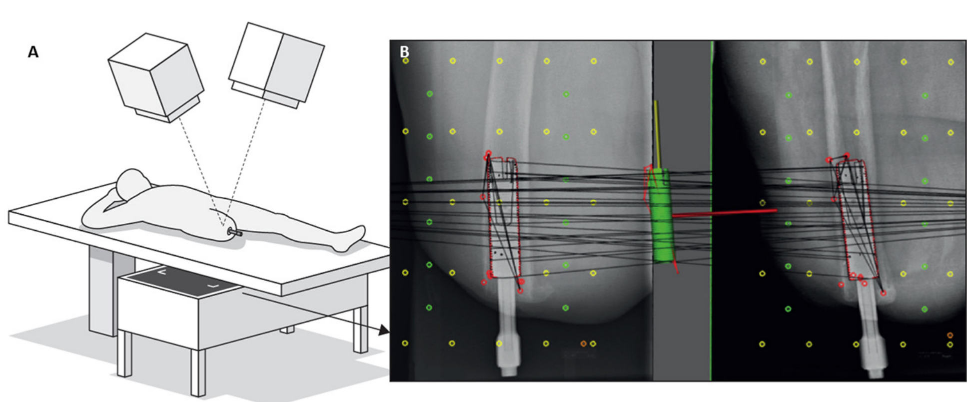

Fig. 2. The setup of radiostereometric analysis. (A) During RSA examination, the roentgen tubes are aligned at a 20° angle with the vertical plane focusing on the fixture as the image is taken. (B) The model-based RSA 4.0 software displays the calibration markers in yellow and green, bone markers in red, and the CAD-model of the OI implant in green fitted to the projected contours of the actual implant on the stereoradiographs (red lines). The Y-axis is the yellow line aligned with the CAD-model.

Table 1
Patients analyzed at each follow-up RSA examination.

Patient count at each interval (months after S2 surgery)							
	1	3	9	12	18	24	60
Patients eligible for follow up	17	17	17	16	14	11	
Patient missing follow up	1	2	1	2	1	1	
Implants removed				3[a]	3		4[b]
Patients analyzed	16	15	16	12	10	10	

[a] 1 abutment and 2 fixtures removed.
[b] 3 abutments and 1 fixture removed.

Table 2
Bacterial findings after 14 deep intraoperative samples from five patients with later OI implant removal.

Bacteria	Numer of isolates
Stapylococcus Aureus	2
staphylococcus lugdunensis	2
Hemolytic streptococcus	2
Peptostreptococcus	1
Enterococcus faecalis	1

2.4. Outcome measures

Translations were assessed along the X-, Y-, and Z-axis. Total translation (TT) was calculated using the 3D Pythagoras theorem $TT = \sqrt{X^2 + Y^2 + Z^2}$. Analysis of later removed implants (RI) and non-removed implants (NRI) were undertaken and the RI group comprised of total implant removal (fixture and abutment) and partial removal (abutment). Peri-prosthetic infection was verified by positive isolation of microorganisms taken from deep representative tissue specimen adjacent to the fixture. A measure of continuous migration was defined as the difference in TT and Y translations between 3 months and 24 months of follow-up. If no difference was found in migration between 3 and 24 months of follow-up the implants were considered stable. The primary outcome was the mean TT and Y translation with standard deviation (SD) after S2 surgery.

2.5. Statistics

Longitudinal implant migration was analysed with a linear mixed model with random effects for patients. Missing values (Table 1) were missing completely at random and therefore all patients were kept in the analysis. Normal distribution was evaluated on qq-plots. Parametric data were analysed using *t* test and non-parametric data were analysed using rank sum and *U* test. A logistic regression analysis was used to determine the predictors (Y and total translations) of implant removal at the last follow-up examinations and the odds ratio (OR) estimated the odds of implant removal during 5 years of follow-up. Precision was assessed by double examinations and reported as the mean difference (SDdif). The measurement error/precision limit was expressed as $\pm 1.96 \times$ precision SD [27]. The mean (SD) of TT was reported instead of the log-transformed values for interpretational reasons. A *p*-value < 0.05 was considered statistically significant. Statistical analysis was performed using STATA 13.1 (Stata Corp LP, College Station, Texas).

3. Results

Six total implant removals (fixture + abutment) and four partial implant removals (abutment) (in total 10 out of 17 (59%) of the implants) were performed during the 60-month follow-up period and one patient did not use the OI-implant (Appendix 1). Fourteen periprosthetic revisions/biopsies were performed in five patients with later OI implant removal and five different bacteria were found (Table 2).

At 24 months, the mean (±SD) distal migration in the RI group of −0.28 mm ± 0.15 mm was higher than −0.01 mm ± 0.12 mm in the NRI group ($p = 0.002$) (Table 3). The migration pattern showed a pronounced distal migration between 18 months and 24 months for removed implants indicating that loosening happened at that time period (Fig. 3). In the RI group, the difference in mean (SD) distal migration from 3 to 24 months (continuous migration) was −0.23 mm ± 0.17 mm ($p = 0.001$) and the difference in TT was 0.65 mm ± 0.69 mm ($p = 0.021$). No group difference in continuous migration was found along the Y-axis ($p = 0.051$) or in TT ($p = 0.39$).

At the last follow-up analysis (Table 4), there was no difference between the groups in Y-axis migration ($p = 0.16$) or TT ($p = 0.76$), but a significant difference from 3 months to last follow-up in TT of the removed implants ($p = 0.009$).

Table 3
Migration of removed (RI, *n* = 6) and non-removed OI implant (NRI, *n* = 4) at 24 months.

	Group	Mean	Median	Standard deviation	Range Min	Max	95% CI Lower	Upper	*p*-value
Absolute migration at 24 months (mm)									
Y-axis	RI	−0.28	−0.25	0.15	−0.37	−0.15	−0.41	−0.16	p = 0.002[a]
	NRI	−0.01	0.01	0.12	−0.39	0.12	−0.12	0.11	
TT	RI	0.97	0.41	0.64	0.39	3.03	0.45	1.49	p = 0.72[a]
	NRI	0.84	0.42	0.52	0.28	1.77	0.32	1.36	
Continuous migration at 24 months (mm)									
Y-axis	RI	−0.23	−0.22	0.17	−0.34	−0.71	−0.36	−0.09	p = 0.001[b]
	NRI	−0.04	−0.06	0.14	−0.20	0.07	−0.17	0.10	p = 0.62[c]
TT	RI	0.65	0.26	0.69	0.01	2.33	0.1	1.21	p = 0.021[b]
	NRI	0.30	0.29	0.60	−0.22	1.13	−0.29	0.88	p = 0.32[c]

TT: Total translations; RI: Removed implants; NRI: Non-removed implants, 95% CI: 95% Confidence intervals.
[a] Difference between the RI and the NRI group.
[b] Changes from early (3 month) to late (up to 24 months) migration in the RI group.
[c] Changes from early (3 month) to late (up to 24 months) migration in the NRI group.

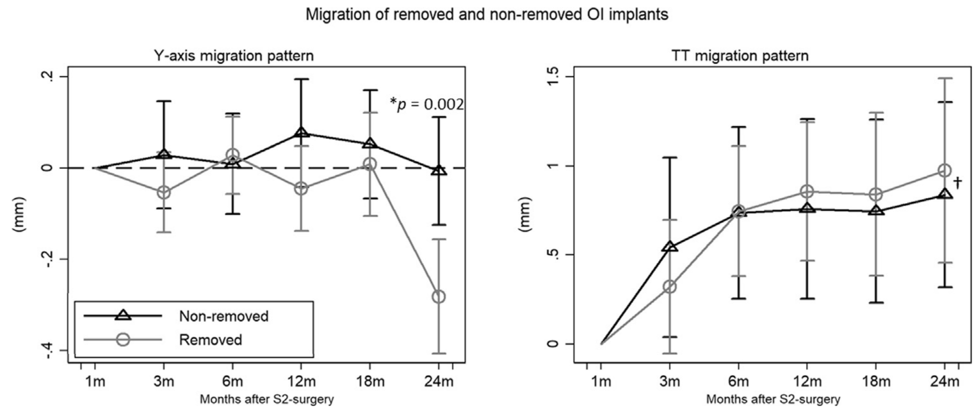

Fig. 3. Mean Y-axis migration and TT pattern with 95% CI of removed versus non-removed OI implants. (*) Significant difference between the removed and non-removed group. (†) Significant changes compared with early migration (3 month) in the removal group.

Table 4
Migration of removed (RI, $n = 11$) and non-removed OI implant (NRI, $n = 6$) at last RSA examination.

	Group	Mean	Median	Standard deviation	Range Min	Max	95% CI Lower	Upper	*p*-value
Absolute migration at last examination(mm)									
Y-axis	RI	– 0.13	– 0.15	0.20	– 0.39	0.19	– 0.25	– 0.01	$p = 0.16$[a]
	NRI	0.01	0.09	0.20	–0.39	0.12	–0.20	0.21	
TT	RI	0.85	0.42	0.90	0.13	3.03	0.25	1.45	$p = 0.76$[a]
	NRI	0.76	0.37	0.71	0.25	1.78	0.02	1.53	
Continuous migration at last examination(mm)									
Y-axis	RI	– 0.07	– 0.07	0.21	– 0.34	0.36	– 0.23	0.08	$p = 0.19$[b]
	NRI	– 0.05	– 0.01	0.11	– 0.20	0.07	– 0.18	0.09	$p = 0.50$[c]
TT	RI	0.55	0.23	0.75	0.07	2.23	– 0.03	1.14	$p = 0.009$[b]
	NRI	0.31	0.17	0.51	– 0.22	1.13	– 0.33	0.95	$p = 0.22$[c]

TT: Total translations; RI: Removed implants; NRI: Non-removed implants, 95% CI: 95% Confidence intervals.
[a] Difference between the RI and the NRI group.
[b] Changes from early (3 month) to late (up to 24 months) migration in the RI group.
[c] Changes from early (3 month) to late (up to 24 months) migration in the NRI group.

Table 5
Precision of RSA determined by double examinations ($n = 12$).

Axis of translation	x	y	z	TT
Mean (mm)	0.06	0.002	-0.06	0.51
SD of difference (mm)	0.20	0.06	0.25	0.28
Precision limit	0.39	0.11	0.49	0.56

TT: Total translations.

The OR of implant removal was 22.5 (95% CI: 1.6 to 314) if the implants migrated distally and 0.04 (95% CI: 0.01 to 0.62) if the implants migrated proximally ($p = 0.021$). For TT, the OR of implant removal was 1.13 (95% CI: 0.31 to 4.08, $p = 0.86$). The precision (SDdif) was 0.06 mm in Y translations and the precision limit was 0.11 mm (Table 5).

4. Discussion

This is the first study using model-based RSA to evaluate osseointegrated implant fixation for transfemoral amputees and to describe the migration pattern of loose and stable implants. We found the stable implants only migrated – 0.01 mm distally until 24 months and they remained in situ after 5 years, whereas later removed implants migrated – 0.28 mm distally. A marker-based RSA study by Nebergall et al. [13] concluded that Integrum OI implants in general had stable fixation since the proximal/distal implant migration was 0.00 mm ($n = 40$) at 24 months and –0.05 mm ($n = 15$) at 5 years. The migration pattern along the Y-axis showed distal migration occurring between 18 and 24 months indicating that loosening leading to later implant removal started around that time-point. Interestingly, we found that distal migration on the last available RSA examination markedly increased the odds (OR = 22.5) of implant removal. Distal migration is the opposite of the loading direction of the OI implant in the femur. The load/pull on the OI implants during gait cycles may play an important role in the migration pattern, and a study of the kinetics in TFA treated with OI implants illustrated that the maximum load on the abutment in the longitudinal axis was 780 N during the stance phase, but decreased down to – 85 N during the swing phase due to the traction created by gravity on the external prosthesis [28]. Even though the magnitude of the distal forces was small, the distal forces are repetitive and do play a role in the causal explanation for the migration pattern of the removed implants. An explanation may be the interrelationship between weight bearing, bone ingrowth and push-out strength, as described in the experimental sheep-study on porous titanium-coated percutaneous implants [29]. Similarly, reduced bone ingrowth into the threaded titanium fixture is possibly related to a limited capacity to withstand weight bearing resulting in increased migration and later OI implant removal.

The precision along the X- and Z-axis in our study was less than the precision in hip stem studies using model-based RSA (SDdif < 0.2 mm) [30,31]. However, the Y-axis precision of 0.06 mm was higher than presented for hip stems [31], probably because the threads on the OI implant helped the CAD-model fitting in the RSA images.

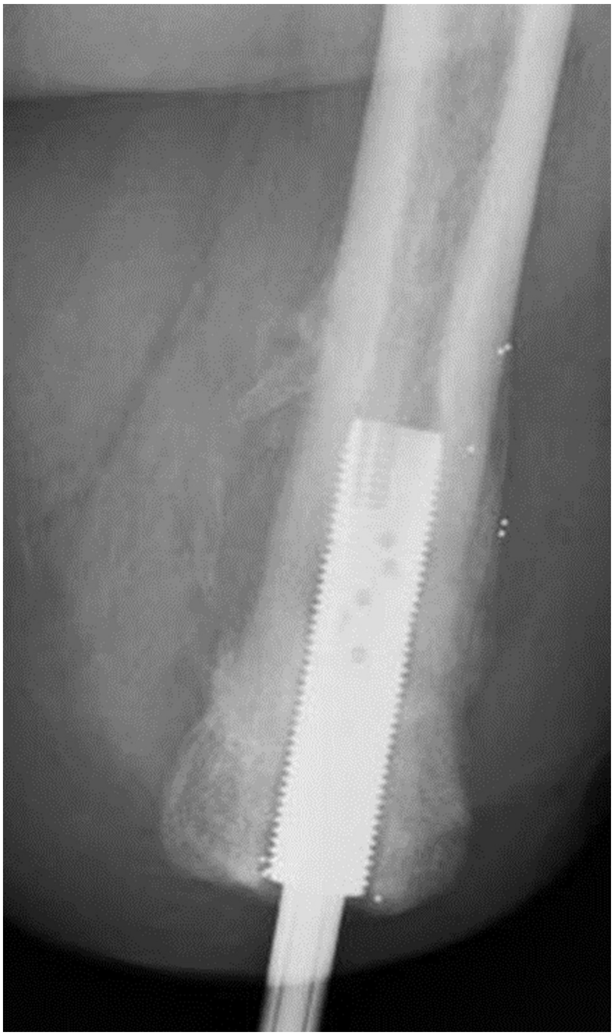

Fig. 4. Chronic periprosthetic infection. Conventional radiograph of the OI implant with a periosteal reaction and periimplant lucency due to a streptococcal periprosthetic infection.

We found that 6 fixtures and 4 abutments were removed within 5 years of follow-up, which is higher than in any other study on implants (OI, ILP, OPL) for transfemoral amputees with > 5 years of follow-up [12,15–17,32,33]. Yet, our results almost match the removal rate (10/15 (66%) OI implants) by the Swedish Osseointegration Team during their first 4 years of experience with the Integrum OI implant. They reported improved implant survival after implementing a standardized rehabilitation protocol [4]. In our study, we used a similar standardized rehabilitation protocol and were not able to reproduce the two-year survival rate of 92% [12] as 8 implants (47%) were removed during the first 26 months because of loosening. In our cohort 5 patients had a deep infection that led to total implant removal; 4 removals were performed within the first 21 months, and 1 (patient O) had a chronic infection that ultimately lead to implant removal after 41 months (Fig. 4). It is difficult to point a single factor leading to implant removal as the population varied in age, cause of amputation, and time since amputation, but patient as well as surgical factors may have played a role.

Generally, infections adjacent to the OI implants are of increasing concern [32]. Lenneras et al. [34] found that 90% of the samples taken from the bone canal around the abutment were colonized with bacteria, which could theoretically increase the risk of an ascending intramedullary infection. Tillander et al. [33] quantified the risk for osteomyelitis by analysing the first 96 patients operated with an OI implant: 16 patients (20%) were diagnosed with osteomyelitis and 10 implants (9%) were removed. They found the most frequent bacteria to be staphylococcus aureus (9/18) followed by coagulase-negative staphylococci (4/18) and a mixed bacteriology similar to the species found in our study [33]. The applied clinical approach to reduce infections is surgical sealing of the skin-implant interface by a reduction of tissue bulk in order to allow skin adherence directly on the distal bone end of the femur [4,35]. We used this approach, but still had a 30% failure rate due to infection (5/17).

Limitations include a small population and data missing at some timepoints (Table 1). However, implant stability and migration can be evaluated acceptably with a small study population due to the high precision of RSA [26]. To handle the missing data a linear mixed model was used to keep all the patients in the analysis. In comparison, a traditional repeated measures ANOVA would exclude the entire patient if just a single timepoint was missing [36]. Seven patients had a high CN (> 120) indicating that the bone-marker model configuration approached a straight line, which decreased the precision around the rotational axis [37]. This is difficult to avoid with a long slim bone model (femur), and therefore, we focused solely on translations. Even though RSA is a precise method and all patients were kept in the analysis, the small sample size may increase the risk of type-II errors; and thus, interpretation of the results should focus on the mean and SD values.

5. Conclusion

We found that removed implants had continuous migration in TT and that distal migration greatly increased the odds of implant removal. The precision of model-based RSA using CAD models was acceptable and highest along the Y-axis. Compared with other OI implant studies a high number of implant removals occurred and in accordance with the phased-introduction of implants concept [25] it is advisable to monitor OI patients closely and preferably with RSA for assessment of implant fixation and loosening patterns. Likewise, and since only a limited number of transfemoral amputees are treated with implants (OI, ILP and OPL) worldwide, osseointegration teams would benefit from multicentre studies and an international registry to clarify complications and advantages of different implant designs.

Disclosure of interest

Professor Langdahl reports grants from Amgen, grants from Novo Nordisk, personal fees from UCB, personal fees from Eli Lilly, personal fees from Amgen, outside the submitted work.

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Authors' contributions

Study design M. Stilling, P.H. Jørgensen, K.K. Petersen, B. L. Langdahl, K. Søballe. Data collection and analysis: R.L. Hansen, M. Stilling. Drafting of manuscript: R.L. Hansen, M. Stilling. Surgical procedures: P.H. Jørgensen, K.K. Petersen. Critical revision of manuscript: M. Stilling, P.H. Jørgensen, K.K. Petersen, B. L. Langdahl, K. Søballe.

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Appendix 1. Presentation of individual migration pattern, clinical data and outcome

ID	RSA data						Clinical data			
	Migration (mm)		Last RSA exam. (months)	Migration difference (mm)		CN of bone model	Cause of amputation	Implant removal	Cause of removal	OI implant in situ (months)
	Y-axis	TT		Y-axis	TT					
A	**0.19**	**1.99**	**12**	**0.09**	**1.99**	**406**	Trauma	++	**Infection**	**21**
B	0.12	0.28	24	0.08	0.69	169	Trauma	–	–	36
C	0.10	0.25	6	0.03	0.25	106	Other	–	–	37
D	**0.10**	**1.05**	**3**	**0.10**	**1.05**	**45**	Trauma	++	**Infection**	**13**
E	0.10	0.32	24	−0.05	0.28	37	Tumor	–	–	54
F	0.09	0.42	24	0.00	0.13	87	Tumor	–	–	58
G	0.02	1.62	24	0.01	0.29	169	Trauma	–	–	45
H	**−0.02**	**0.13**	**24**	**0.03**	**0.16**	**58**	Trauma	+	**Pain**	**26**
I	**−0.05**	**0.89**	**6**	**0.02**	**0.89**	**107**	Infection	+	**Pain**	**11**
J	**−0.07**	**0.35**	**6**	**−0.06**	**0.35**	**85**	Other	++	**Trauma**	**12**
K	**−0.15**	**0.40**	**24**	**−0.06**	**0.38**	**222**	Thrombosis	+	**Pain**	**25**
L	**−0.16**	**0.24**	**12**	**−0.10**	**0.24**	**48**	Trauma	++	**Infection**	**12**
M	**−0.18**	**0.42**	**24**	**0.01**	**0.21**	**125**	Other	+	**Pain**	**40**
N	**−0.32**	**0.39**	**24**	**−0.66**	**1.57**	**69**	Infection	–[a]	**Pain**	**34**
O	**−0.37**	**3.03**	**24**	**−0.82**	**3.36**	**NA**	Tumor	++	**Infection**	**41**
P	**−0.39**	**0.42**	**12**	**−0.44**	**0.42**	**92**	Trauma	++	**Infection**	**10**
Q	−0.39	1.78	24	−0.30	0.74	389	Other	–	–	54

[a] Patient N does not use the OI implant due to pain, but uses instead a modified prosthetic socket, thus considered an OI implant failure.

Implants migrating above the Y-axis precision limit (0.11 mm) are presented in grayscale rows.Implant removals are highlighted with bold font.Migration (mm) measured from baseline to the last RSA examination (months after Stage 2 (S2) surgery (the percutaneous abutment was connected to the fixture at stage 2)).Migration difference (mm) measured as implant migration between the last 2 follow-up examinations.CN of bone model where >120 indicates poor distribution of stabile/useful bone markers.Cause of amputation in terms of indication leading to the transfemoral amputationRemovals, total OI implant removal (++) or removal of abutment(+).Cause, in terms of cause of removals.OI implant in situ in terms of the number of months after S2 surgery the fixture or abutment remained in the patient.RS: Aradiostereometric analysis; TT: Total translations; CN: condition number

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