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Osteointegrative Sleeves for Metaphyseal Defect Augmentation in Revision Total Knee Arthroplasty: Clinical and Radiological 5-Year Follow-Up

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ABSTRACT

Background: Cementless metaphyseal implant fixation of revision total knee arthroplasty has encouraging early results. We analyzed midterm results and implant survival of osteointegrative augments in Anderson Orthopedic Research Institute (AORI) type 2a, 2b, and 3 defects. Reasons for implant failure were explored and the potential for anatomic joint line reconstruction evaluated.

Methods: Sixty-seven consecutive patients (68 revision total knee arthroplasties) received cementless metaphyseal sleeves between 2011 and 2014. The mean follow-up was 5.0 years, mean age was 68.5 years, and mean body mass index was 31.4 kg/m². The clinical and radiographic results were determined using established scoring systems. Additionally, the survival rate was calculated and reasons for failure were analyzed.

Results: In 2 patients (4.3%), sleeves had to be removed early postoperatively for deep infection after second-stage reimplantation. With continuously functioning remaining implants, the aseptic survival rate was 93.6%. Cleared up for initial technical issues due to poor bone quality, it is as high as 98%. The scores remained to be significantly improved by 64.8 points (Western Ontario and McMaster Universities Osteoarthritis Index) and 25.8 points (Knee Society score) ($P < .001$). In 10 patients (29.4%), diaphyseal radiolucencies were observed without suspicion of loosening. The mean joint line was noted to be 0.36 mm lower to the anatomic level.

Conclusion: At a mean follow-up of 5.0 years, cementless osteointegrative sleeves for metaphyseal fixation in AORI 2a, AORI 2b, and AORI 3 defects yielded continuous implant fixation even in cases with preceding revisions. The cleared up aseptic survival rate was 98% at 5 years. The modular sleeve design allowed joint line reconstruction near the anatomic level.

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Total knee arthroplasty (TKA) is a safe and successful procedure in end-stage knee osteoarthritis [1]. In many countries, the number of performed primary knee arthroplasties is on the rise [2–6]. In spite of innovations in the last decades including surgical techniques, materials, and implant design, the durability of TKA is still limited [7–9]. Implant alignment, fixation, and periprosthetic

osteolysis caused by polyethylene wear comprises some reasons for bony defects [10]. These may be additionally enlarged during the explantation process of the loosened implants. In these deficient bone situations, accurate positioning and durable fixation of the revision components are subsequently compromised. Up to date these revision cases are surgically demanding, resulting in prolonged operation time and hospital stay, and are often complicated due to surgical problems and the possibility of limited implant survival. Last but not least, revision total knee arthroplasty (rTKA) constitutes a certain burden on the patient and the healthcare system [11,12]. Consistent with the growing number of primary TKA, the number of rTKA also increased [2–6]. Contemporary procedures for compensation of large metaphyseal bone defects are

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auto-/allogene bone impaction grafting and utilization of bone cement or cemented metal blocks [13–15]. However, a durable cemented augmentation cannot always be achieved. Although adequate short-term results were described, mechanisms of resorption and signs of fatigue are an obstacle to long-term success [14,16–22]. The modular cementless metaphyseal fixation has been successfully established in total hip arthroplasties for several years [23]. Modern revision knee systems took up these principles by using osteointegrative metal sleeves with a specially structured surface supporting bony ingrowth and enhancing durable stable fixation by biologic, cementless technique [24].

This retrospective study aimed at investigating clinical and radiographic 5-year results in patients with cementless osteointegrative metaphyseal sleeves applied for large metaphyseal defects following failed TKA and rTKA. To establish and to compare clinical and radiographic results, validated scores were administered. The radiographic investigation concentrated mainly on osteointegration and radiolucencies as potential markers for implant loosening. Additionally, the joint line and the potential of the system to reconstruct the anatomic level were considered. The implant survival rate was calculated and possible reasons for implant failure were discussed.

Patients and Methods

Between January 1, 2011, and December 31, 2014, all patients who received cementless metaphyseal fixed sleeves were identified at a single academic referral center. By agreement, the institution has to accept all referrals of affiliated clinics.

All sleeves were partially poro-coated and combined with cementless stems. Bone cement was only used in the epiphysis below the tibial baseplate, paying attention to not contaminating the porous coating of the sleeve. Six patients had to be excluded from this series. Three of them were primary TKAs with bony defects in combination with severe malalignment and/or instability. One patient received sleeves for posttraumatic knee osteoarthritis. Due to fracture malalignment of the femur, a stem could not be used; however, the sleeve alone yielded metaphyseal fixation. In addition, in 2 patients sleeves were applied to compensate metaphyseal defects due to removal of a giant cell tumor.

After exclusion of the primary TKA, tumor, and malaligned fracture cases, 61 consecutive patients with 62 cases of sleeve implanting rTKA remained and were included. In 31 cases (50.0%), the implantation of sleeve-fixed components was the first revision, after failed primary TKA, in 25 cases (40.3%) the second, in 5 cases (8.1%) the third, and in 1 case (1.6%) the fourth. In 3 cases (4.8%) a femoral sleeve, in 22 cases (35.5%) a tibial sleeve, and in 37 cases (59.7%) a femoral and tibial sleeve were implanted.

The 49 females (79.0%) and 13 males (21.0%) had a mean age of 68.5 (± 9.7 ; 38.0–83.0) years and a mean body mass index (BMI) of 31.4 (± 6.4 ; 19.1–46.4) kg/m². The indication for 39 rTKA (62.9%; 10 femoral, 17 tibial-femoral, 12 tibial) was aseptic loosening of the primary or revision TKA. In 4 cases (6.5%), revisions were done due to instability, 2 (3.2%) because of malrotation of the implants, and 17 cases (27.4%) were revised because of septic loosening. All revised patients had large bony defects which were intraoperatively classified according to the Anderson Orthopedic Research Institute (AORI) [25]. Bone loss was characterized in intact metaphyseal bone (AORI type 1), damaged metaphyseal bone loss with loss of one condyle (AORI type 2a) or both condyles (AORI type 2b). Also a small entity of AORI type 3 defects with deficient metaphyseal bone was seen [25].

For evaluation of the preoperative health status, the score of the American Society of Anesthesiologists (ASA) was used [26]. For the present study, the classes ASA 2 (mild chronic disease), ASA 3

(severe chronic disease), and ASA 4 (severe chronic disease with acute life-threatening event less than 3 months ago) were relevant.

Routine preoperative workup comprised bloodwork, including C-reactive protein and interleukin 6. In cases where periprosthetic joint infections (PJI) were suspected, an aspiration for cell count and microbiology test was conducted. In case of PJI, a 2-stage rTKA (first-stage: molded antibiotic-impregnated cement spacer and adjuvant systemic antibiotics; second-stage: 6–12 weeks later with negative infection parameters and negative joint aspiration) was performed.

Intraoperative diagnostic workup included tissue samples for microbiology and histologic classification according to Krenn [27]. This retrospective study was approved by the local ethics committee.

Surgical Procedure

A medial-parapatellar arthrotomy was performed. After a complete synovectomy, removal of the previous implants respectively cement-spacer and an osseous debridement followed. The bony defect size according to AORI was noted and the ligament situation including joint line and flexion/extension gaps were assessed. The preparation of the metaphysis was performed with broaches. The size was deemed appropriately when the broach was rotationally stable. The top of the last broach served as a tibial resection guide with an integrated 2° slope and intramedullary reference. On the femoral side, an intramedullary reamer/guide was used. The asymmetric broaches were analogically impacted until the chosen size and position showed rotational stability and a restored joint line. The next steps comprised the distal resection in 5°/7° valgus, assessment of distal and posterior augments and notch preparation. All patients received M.B.T Revision Tibia-trays with varus/valgus constrained inlays (SIGMA TC3 RP, DePuy Synthes, Warsaw, IN), when possible ($n = 24$, 51.1%). The same M.B.T. Tray also accepts hinged rotating platform insert S-ROM Noiles (DePuy Synthes, Warsaw, IN), which had to be used in cases of severe instability in AORI 2a, 2b, and 3 defects ($n = 23$, 48.9%). The surgical steps except the distal femoral preparation are identical because sleeve and stem sizes are the same. All patients received cementless partially poro-coated sleeves on the tibial and femoral side.

Demographics

Of the 61 patients, 15 patients were lost to follow-up: 2 patients were deceased at time of contact, 2 patients had dementia, 4 patients moved and current contact data could not be established, and 7 patients refused the participation in the study. As a result, the statistic group for clinical evaluation consisted of 46 patients (47 cases). All patients were available for clinical but 7 not for radiographic review. The preoperative health status of the 46 patients (47 cases) was categorized as follows: 21 patients (45.6%) as ASA 2; 24 patients (52.2%) as ASA 3; and 1 patient (2.2%) as ASA 4.

Scores and Classifications

The histologic analysis of intraoperative gained samples of periprosthetic membranes is considered to give additional information on the failure mechanism. The classification according to Krenn et al [27] differentiates between 4 types of loosening: wear-induced (type I), infection-induced (type II), mixed-induced with criteria of wear-associated and septic-associated loosening (type III), indifferent-induced without criteria of wear-associated and septic-associated loosening (type IV).

The clinical results were established using the self-administered Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) in the German version with 24 questions, ranging from 0 (good clinical result) to 10 points (poor clinical result) [28]. The Knee Society score (KSS) was applied during clinical follow-up to collect clinical data. It was divided into the functional (KSSfs) and the clinical section (KSScs), 100.0 points respectively being the maximum value for the best result. The values were graded according to the following classification [29]: 80.0–100.0, excellent; 70.0–79.0, good; 60.0–69.0, fair; below 60.0, poor.

Radiographic Analysis

For radiographic evaluation, anteroposterior and axial X-rays of the knee were used. The medial-lateral width of the implanted stem of a certain size is known due to the round profile independent of deviations in X-ray projections. OrthoView software (Jacksonville, FL) was used and X-rays were calibrated using the true magnification to perform the measurements, eliminating the magnification-related source of inaccuracy [30]. Measurements were taken by 2 experienced orthopaedic surgeons. For retest accuracy, an intraobserver reliability study was conducted before measurements. The calculated intraclass correlation for the radiolucent lines in Knee Society Total Knee Arthroplasty Roentgenographic Evaluation and Scoring System (KSRESS) was 0.85 and for the transepicondylar axis width ratio (TEAW), it was 0.76. Both indicated a good reliability [30,31].

In accordance with the KSRESS, radiolucencies with >1 mm periprosthetic distance were documented for sleeve fixed components (Fig. 1). All radiolucent distances in the respective zones were measured and cumulated for each anatomic region and projection (tibial anteroposterior, tibial axial, and femoral axial). For the combined radiolucent lines (sums), the following graduation was used in accordance with the established original KSRESS [32]:

- 4.0 mm or less: aseptic loosening is probably not significant.
- 5.0–9.0 mm: should be closely followed.
- 10.0 mm or greater: aseptic loosening is significantly possible.

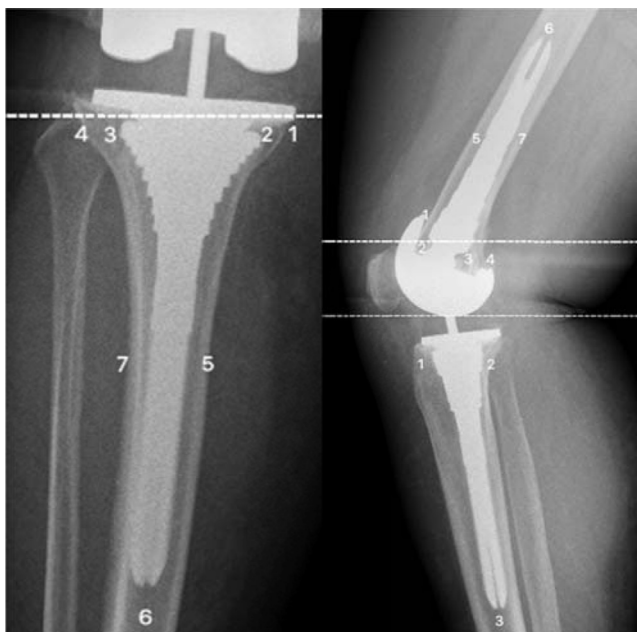


Fig. 1. Example for the periprosthetic zones according to KSRESS. In the anteroposterior view, only the tibial component was analyzed. KSRESS, Knee Society Total Knee Arthroplasty Roentgenographic Evaluation and Scoring System.

- 10.0 mm or greater: aseptic loosening is significantly possible.

To determine probable or definite loosening by radiographic criteria, the established KSRESS was applied solely. To differentiate between the coated and uncoated parts of the sleeve (not considered in the KSRESS), the periprosthetic bone around the porocoated part of the sleeve was subdivided (Fig. 2). This is not only for future reference, but to analyze potential sources for failure.

To measure the level of joint line, the TEAW was used [33]. The TEAW is defined as the distance between the medial and lateral epicondyle of the distal femur (ie, Fig. 3; 95.59 mm). The ideal level of the reconstructed joint line is placed at 1/3 TEAW distal of the lateral epicondyle (ie, Fig. 3; 28.59 mm). In Figure 3, the red line demonstrates the actual joint line (27.41 mm). The difference between the ideal and the actual joint line described, if the actual joint line is placed more proximal or distal in correspondence to the ideal level (Fig. 3; 1.18 mm more proximal). The measurement of the TEAW was impossible in 8 cases because of severe bone defects of the epicondyles which serve as anatomic landmarks.

Statistical Analysis

The implant longevity was described by Kaplan-Meier analysis. For comparison between the preoperative and postoperative score values, the dependent sample *t*-test was used. In addition, the clinical outcome of patients with a displacement of the joint line <5 mm and ≥5 mm was compared by using independent sample *t*-test [34].

The collected data underwent pseudonymization and were transferred to IBM SPSS Statistics (IBM SPSS Statistics, version 24.0.0.0, 64-bit version) for statistical analysis.

Results

The following results were based on 47 cases with 39 females (83.0%) and 8 males (17.0%). At time of surgery, the mean age was 67.2 (±9.2; 38.0–82.0) years. The mean BMI was 30.6 (±5.4; 19.1–42.2) kg/m², representing first-degree obesity according to World Health Organization. In 28 (59.6%) cases, the operation was performed on the left and in 19 (40.4%) cases on the right side. The surgeries were performed by senior arthroplasty surgeons. In 26 (55.3%) cases, the implantation of sleeve-fixed components was the first revision, in 17 (36.2%) cases the second, in 3 (6.4%) cases the third, and in 1 (2.1%) case the fourth. In 3 cases (6.4%) a femoral sleeve, in 17 cases (36.2%) a tibial sleeve, and in 27 cases (57.4%) a femoral and tibial sleeve were implanted for AORI >2a (Table 1). On the femoral side, most patients received the largest sleeve size (46 mm) and in 12 patients the revision knee system included a diaphyseal stem fixation without the use of a sleeve. In contrast to that, all stems were combined with a sleeve on the tibial side.

The mean duration of surgery was 202.3 (±68.7; 96.0–374.0) minutes and the mean length of stay was 12.0 (±3.4; 7.0–25.0) days. In 31 cases (66.0%), the surgery was performed in 1-stage technique. Two of these showed a type III histology result with wear-induced and septic-induced criteria. During follow-up, no complication developed, except for a positive *Staphylococcus epidermidis* culture in 1 patient. Preoperative clinical laboratory findings and the intraoperative situs indicated no hint for a PJI. Because the pathogen was found in 1 of 5 tissue samples, it was considered as possible septic loosening, hence treated prophylactically by antibiotics. An infection did not occur later on. The other 16 (34.0%) cases were performed in 2-stage surgery, whose histologic results showed type II according to Krenn in 10 cases and type III in 2 cases. A strong suspicion of low-grade PJI in 4 patients was not confirmed by microbiology nor by histology (all type IV; Table 2).

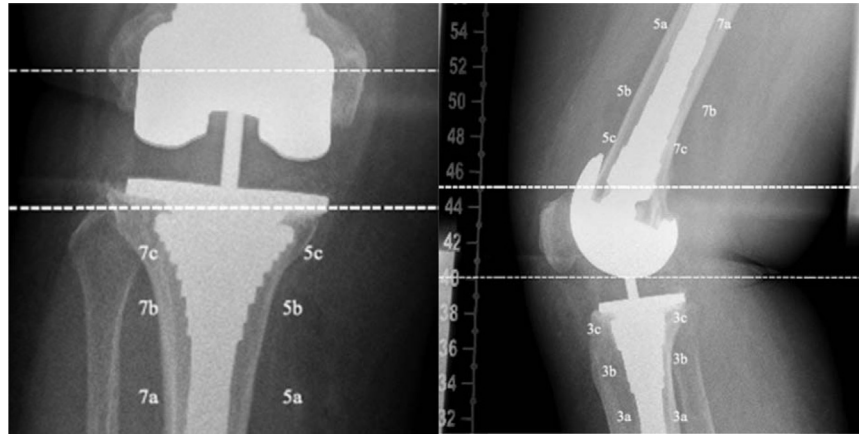


Fig. 2. Periprosthetic zones for additional examination of radiolucent lines around the sleeves. Poro-coated part of the sleeve (zones 3, 5, 7c), uncoated (zones 3, 5, 7b), and diaphyseal stem (zones 3, 5, 7a).

Survival Rate

After a mean follow-up of 5.0 (± 1.2 ; 2.1-6.9) years, there were 3 patients with an aseptic loosening (aseptic implant survival rate, 93.6%). The septic implant survival rate was 93.6% by 2 cases of early and 1 case of late PJI. The implant survival rate for any reason with removal of the sleeve-fixed endoprosthesis was 87.2% (Fig. 4).

Three aseptic failures occurred. The first patient (man; 70 years; BMI, 28.7 kg/m², ASA 3) had a history of 2 aseptic failures, before implantation of an S-ROM knee system in femoral 2a and tibial 2b defects. The lateral tibial bone loss was so severe intraoperatively so that the surgeon decided to use additional polymethylmethacrylate (PMMA) cement filling laterally, resulting in an uncommon hybrid fixation. After an interval of 3 years free of complaints, the lateral cortical bone was radiologically thinned out and subsequently fractured. The tibial component loosened and a 1-stage revision had to be performed. The next case (woman; 62 years; BMI, 39.1 kg/m², ASA 2) had a history of a 1-stage revision in advance of being revised to an S-ROM knee system for femoral type 2b and tibial 2a defect situations. After a complaint-free interval of 3 years, the patient sustained a direct trauma and was diagnosed in a different clinic. There she finally underwent complete 1-stage revision for patella subluxation and instability. More details could not be obtained for the study. The last case (man; 69 years; BMI, 24.4 kg/m², ASA 2) had a history of two 1-stage revisions including a

periprosthetic femoral fracture before being converted to an S-ROM knee system. The indication was aseptic femoral and tibial loosening of the cemented implants of the previous rTKA. Intraoperatively, a femoral type 2b and tibial type 3 bone loss was found. The tibial base plate had to be placed 9 mm below the head of the fibula. The anterior cortical bone was thinned out at that point up to 1.5 mm. Consequently, a smaller sleeve size had to be used, and again PMMA was used in an unusual fashion to fill an anterolateral defect. It has to be said that these 2 failure cases were the only ones in the whole series where PMMA was additionally used to fill smaller defects. The proximal part of the sleeve intended for cementless use was partially uncovered resulting in a compromised bony contact. After an interval of 5 years without complaints, the anterior cortex flawed and a tibial implant loosening occurred with subsequent loosening of the femoral sleeve. A 1-stage revision was performed with exchange of all components.

Two septic failures (deep PJI) occurred early after revision surgery. The implants had to be removed 54 days and 100 days after implantation of sleeve-fixed rTKA. In the first case (woman; 68 years; BMI, 31.1 kg/m², ASA 3), the patient had a history of 2 previous revisions for deep PJI (1 and 2 stage) and received an S-ROM knee system with femoral and tibial sleeves (AORI 2b defects femoral and tibial) in a subsequent 2-stage procedure. Multi-resistant staphylococci were identified at time of removal. The second case (woman; 45 years; BMI, 33.9 kg/m², ASA 2) was diagnosed with severe rheumatic arthritis and had a history of 3 septic 2-stage revision before referral. Having AORI 2a (femoral) and 2b (femoral) defects, she underwent another 2-stage revision with sleeve-fixed TC3 implants. After removal, staphylococci were identified and an arthrodesis had to be done later on. The third septic failure occurred under somewhat irregular circumstances. The patient with rheumatoid arthritis (woman; 38 years; BMI, 31.2

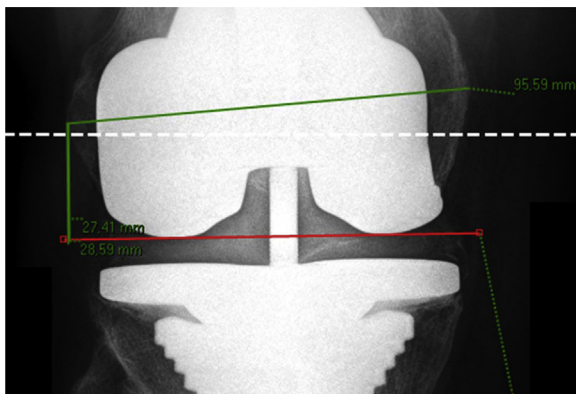


Fig. 3. Example for measurement of the joint line according to TEAW. The reconstructed joint line is placed 1.18 mm more proximal. TEAW, transepicondylar axis width ratio.

Table 1
Intraoperative Bone Loss as Classified by the AORI.

AORI	N (Femoral)	%	N (Tibial)	%
Type 1	10	21.3	2	4.2
Type 2a	13	27.7	20	42.6
Type 2b	22	46.8	21	44.7
Type 3	2	4.2	4	8.5
Total	47	100.0	47	100.0

Damaged metaphyseal bone loss with loss of one condyle (AORI type 2a) or both (AORI type 2b) and deficient metaphysis as AORI type 3. AORI, Anderson Orthopedic Research Institute.

Table 2
Histologic Classification of Periprosthetic Membranes According to Krenn.

Histologic Classification	N	%
Krenn type I	13	27.7
Krenn type II	10	21.3
Krenn type III	4	8.5
Krenn type IV	20	42.5
Total	47	100.0

Wear (type I), infection (type II), mixed with criteria of wear-associated and septic-associated loosening (type III), indifferent without criteria of wear-associated and septic-associated loosening (type IV).

kg/m², ASA 2) already had multiple revisions for PJI before receiving an S-ROM knee system in AORI type 2a (femoral/tibial) in a 2-stage procedure. She was doing fine for 3 years with fixed implants radiographically. Having anterior knee pain, she went to another clinic where the patient received an isolated retropatellar resurfacing. Subsequently another deep PJI occurred with staphylococci and implants had to be removed. More details were not available for this study.

Clinical Outcome

Omitting the 6 failure cases, the clinical results of the 41 remaining cases improved in WOMAC from a preoperative mean of 155.8 (± 58.6 ; 0.0–233.0) to 91.0 (± 52.5 ; 0.0–208.0). Significant improvement was found in the categories “pain,” “stiffness,” and “activity” ($P < .001$). The KSS increased from a mean of 104.4 (± 34.1 ; –10.0 to 174.0) to 130.2 (± 30.2 ; 40.0 to 92.0; $P < .001$). Postoperative values of the clinical score were 72.8 (± 13.0 ; 40.0–95.0), increasing from 56.6 (± 16.4 ; 10.0–94.0; $P < .001$) and the postoperative values of the functional score 57.4 (± 21.4 ; 0.0–100.0), increasing from 47.8 (± 23.2 ; –20.0 to 80.0; $P < .001$).

Radiological Outcome

The radiological follow-up revealed in 23 cases no radiolucency. In 11 cases, a radiolucency >1 mm was found in 1 zone (5 patients), 2 zones (3 patients), 3 zones (2 patients), and 4 zones (1 patient; Table 3). Except for 1 case, all radiolucencies were located diaphyseal. One patient (69 years, BMI, 27.0 kg/m²) showed a cumulated amount of lucent lines of 6.4 mm (zones tibial anteroposterior 6, lateral 3/femoral lateral 6, 7). Having no clinical symptoms, he is followed up regularly. At time of last examination, the patient had a

good joint function without clinical suspicion of loosening. The remaining 10 cases showed an amount <4 mm (Table 3).

Of the 11 cases, 5 cases had metaphyseal radiolucencies which were looked at more closely in the separate analysis of the periprosthetic area around the sleeves. All were located in the uncoated parts (Table 4).

Of the 33 patients with preserved epicondyles for TEAW, the joint line was elevated in 17 cases and the joint line was lowered in 16 cases. The mean joint line was 0.36 (± 4.1 ; –11.7 to 6.96) mm lower to the measured anatomic level. A correlation between the level of the postoperative joint line and the clinical outcome was not statistically significant ($P > .05$), neither between patients with a displacement of the joint line <5 mm and ≥ 5 mm ($P > .05$).

Discussion

In rTKA, the augmentation of bony defects is an integral part of surgery. Small areas of bone loss (AORI 1) can be reconstructed by using PMMA or allogeneic bone. For higher grade of bony defects (AORI 1–2), metal blocks can be connected to implants [13–15]. Although these established techniques revealed good results in short term, resorption and fatigue processes have been described [14,16–22]. As a result, a repeated failure of the revision implant could occur. This is devastating for the patient and produces an additional burden for the healthcare system [11,12]. Contemporary revision knee systems increasingly focus on metaphyseal bone for defect augmentation and implant fixation both cemented and cementless [35].

In this retrospective study, the augmentation of large metaphyseal bony defects with a biological fixation through osteointegrative sleeves in rTKA was analyzed. Because of a great diversity of intraoperative bone loss situations and a possible range between preoperative and intraoperative size of defects, prospective, randomized studies are difficult to perform. One reason for that is the variety of revision implants (short/long stem, cemented/cementless, offset-adapters), which could result in a heterogenic control group. Although the surgeries were performed in a certified academic referral center, findings of large bony defects (AORI 2a, 2b, 3) in rTKA represent a small entity.

Primary TKA was excluded, leaving a group of patients with a BMI of 30.6 kg/m² (obesity grade I patients) with mainly ASA 2–3 score. Interestingly, the study group consisted predominantly (80%) of female participants. This observation has been made before by Stefani et al and others [36,37] who found to have up to 71% females in their groups of patients with metaphyseal defects. A certain age

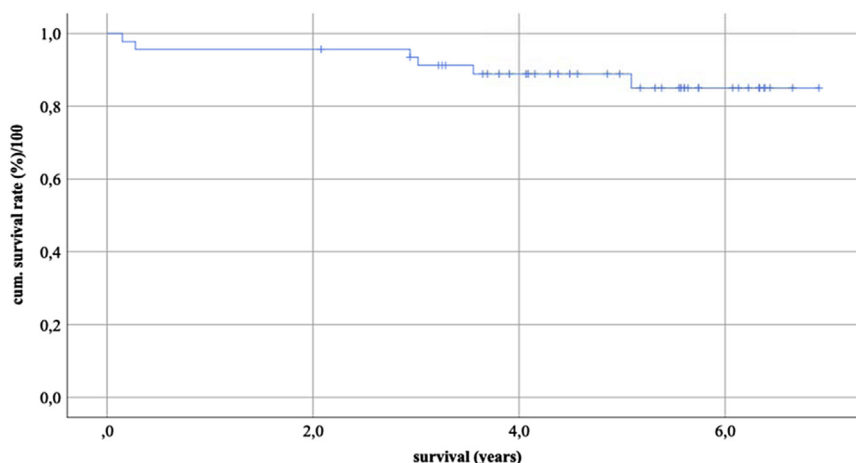


Fig. 4. Kaplan-Meier analysis for implant survival. The overall implant survival was 87.2%.

Table 3
Radiolucencies >1 mm at Time of Final Follow-Up.

KSRESS Zone	1 Zone (5)					2 Zones (3)			3 Zones (2)		4 Zones (1)	Total
	1	2	3	4	5	6	7	8	9	10	11	
Femur lateral												
1												0
2												0
3												0
4												0
5		1					1		1			3
6						1				1	1	3
7			1	1				1	1	1	1	6
Tibia anteroposterior												
1												0
2												0
3												0
4												0
5					1			1				2
6									1		1	2
7												0
Tibia lateral												
1	1											1
2												0
3						1	1			1	1	4

Regional subdivision in zones according to the KSRESS. Radiolucencies were mainly found around the diaphyseal zones (5, 6, and 7 tibia anteroposterior and femur lateral; 3 tibia lateral, respectively).

KSRESS, Knee Society Total Knee Arthroplasty Roentgenographic Evaluation and Scoring System.

and gender-related risk of bone loss and postmenopausal osteoporosis with a significant decline in connective tissue progenitors in elderly women have been described by Muschler et al [38]. However, further investigations regarding gender-related differences in metaphyseal bone quality as possible failure mechanism for TKA failure seem appropriate. Nonetheless, a relatively homogenous and representative group of patients with devastating bony defects following primary or revision TKA were assembled and gathered suitable for evaluation.

In our patient group, the preoperative WOMAC improved from 155.8 (±58.6; 0.0–233.0) to 91.0 (±52.5; 0.0–208.0) points ($P < .001$). The statistical significance was not only demonstrated for the complete score, but also in the 3 subcategories. Huang et al [39] also

analyzed the clinical outcome with the WOMAC in 119 cementless sleeves and showed a similarly significant improvement in short-term results. Furthermore, in this study, the KSS improved from preoperative 104.4 (±34.1; –10.0 to 174.0) to the last time of follow-up to 130.2 points (±30.2; 40.0 to 192.0; $P < .001$). Similar increases were found by Graichen et al [40], who presented an increase of 59.0 points in a group of 121 patients with a mean follow-up of 3.6 years (total postoperative score 147.0 points, starting at preoperative 88.0 points). Another study performed by Watters et al [41] included 98 patients and showed an improvement in KSS from 85.0 points to 157.0 points after a mean follow-up of 5.3 years. In analogy to the present study, the analyzed defect size in both studies was described as at least 2a according to AORI. In KSSCs, the data of this study showed a statistical improvement from preoperatively 56.6 (±16.4; 10.0–94.0) points to 72.8 (±13.0; 40.0–95.0) points after surgery ($P < .001$). After a mean follow-up of 2.75 years, Alexander et al [42] documented 92 points in KSSCs in 28 patients with tibial type 2b-3 defects, a value that had increased from 55.0 points before surgery. In another study by Barnett et al [43], the KSSCs improved in patients with type 2 or 3 defects from 41.7 to 88.7 points after a mean follow-up of 3.17 years. Dalury and Barrett [44] showed a postoperative KSSCs of 90.0 points in 40 patients after 4.8 years, starting at 36.0 points at time before surgery. In the study by Bugler et al [45], cemented sleeves were included. After a mean follow-up of 3.25 years, the 35 patients showed 81.3 points in KSSCs, a value similar to that noted before in studies with cementless metaphyseal fixation. In KSSfs, this study documented an improvement from 47.8 (±23.2; –20.0 to 80.0) to 57.4 (±21.4; 0.0 to 100.0) points ($P < .001$). Huang et al showed similar values (47.9 points to 61.1). In the study by Barnett et al, the mean postoperative results of 75.0 points are slightly better [43].

Compared to the study of Chalmers et al, we had 44 (49) uncemented tibial sleeves and 30 (54) femoral sleeves. The BMI 30.6 kg/m² (34) is also similar; however, the number of second, third, and even fourth revisions after failed TKA is higher in our patients. The number of previous surgeries might influence the bone quality and the local potential of osteointegration. This might be one reason for the lower survival rate of 93.6 (96/99.5) as well as the longer follow-up period: at the mean 5.0 years (3.2) [35]. In

Table 4
Number of Patients With Radiolucent Lines >1 mm at Final Follow-Up.

KSRESS Zone	Patient No.				
	2	5	6	10	11
Femur lateral					
5a	1				
7a				1	1
5b	1				
7b				1	1
5c					
7c					
Tibia anteroposterior					
5a					
7a					
5b		1			
7b					
5c					
7c					
Tibia lateral					
3a			1		
3b			1		
3c					

Subdivision of the zones in coated (c) and uncoated part (b) of the metaphyseal sleeve and the diaphyseal stem (a). Radiolucencies were mostly found around the uncoated sleeve and stem fixation.

KSRESS, Knee Society Total Knee Arthroplasty Roentgenographic Evaluation and Scoring System.

retrospect, 2 of the aseptic failures in our series were related to tibial loosening subsequent to severe bone loss and likely insufficient implant fixation/technical issues.

In these cases of severe type 2b and type 3 tibial defects with brittle cortical bone, alternative methods of fixation should be considered. The third aseptic failure in a patient with a BMI of 39.1 kg/m² is likely related to a direct trauma with subsequent patellar subluxation and revision in a different clinic. In the septic failures, young age and rheumatoid arthritis can be identified as risk factors [46].

In our study, the radiological evaluation showed mainly diaphyseal radiolucencies according to KSRESS. These findings were in contrast to the results by Fedorka et al [47]. The authors analyzed 50 patients with a sleeve-fixed revision knee system after a mean follow-up of 4.9 years and found the most radiolucencies in zone 1, as opposed to zones 5 and 7 in our study. Huang et al presented similar results compared to our study and described diaphyseal radiolucent lines. In the separate analysis of the periprosthetic bone around the sleeve component, we found radiolucencies in the uncoated areas, whereas there was no radiolucency in the porocoated part, suggesting a biological fixation/osteointegration. The accumulation of diaphyseal radiolucent lines may be explained by a pivot in spite of well-fixed implants. Although the metaphyseal sleeves showed osseous integration, there is a possibility of pivoting especially in combination with long diaphyseal stems [48]. In addition, the diaphyseal pivoting might be enhanced due to higher mechanical stress in varus/valgus constrained or rotating-hinged implants [46].

A similar technique to achieve a metaphyseal fixation in rTKA is the use of cones. As opposed to sleeves, the revision knee system is fixed into the cone with PMMA. First studies with short- and mid-term follow-ups with a defect augmentation using cones showed comparable clinical outcomes and survival rates to the illustrated results in patients with a sleeve fixation [49,50]. Potter et al [51] presented 5-year results in KSSCs about 65.0 points and the overall survival rate for any cone revision about 84.0%. Further prospective, randomized studies between sleeves and cones will be needed to acquire the best biological fixation method in metaphyseal bone loss situations in rTKA.

Conclusion

At a mean follow-up of 5 years, cementless osteointegrative sleeves used for metaphyseal fixation in AORI 2a, 2b, and 3 defects yielded continuous implant fixation with acceptable clinical results and patient satisfaction even in cases with preceding revisions. The aseptic survival rate was 93.6% at 5 years. Cleared up for possible initial technical issues due to poor bone quality, it is as high as 98%.

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