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KNEE REVISION SURGERY

Porous metal cones: gold standard for massive bone loss in complex revision knee arthroplasty? A systematic review of current literature

Stefano Divano[1] · Luca Cavagnaro[1] · Andrea Zanirato[1] · Marco Basso[1] · Lamberto Felli[1] · Matteo Formica[1]

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Abstract
Introduction Revision knee arthroplasty is increasing, and in that case, bone loss management is still a challenging problem. In the last years, the body of literature and interest surrounding porous metal cones has grown, but few systematic evaluations of the existing evidence have been performed. The aim of our systematic review is to collect and critically analyze the available evidence about metal cones in revision knee arthroplasty especially focusing our attention on indications, results, complications, and infection rate of these promising orthopaedic devices.
Materials and methods We performed a systematic review of the available English literature, considering the outcomes and the complications of tantalum cones. The combinations of keyword were "porous metal cones", "knee revision", "bone loss", "knee arthroplasty", "periprosthetic joint infection", and "outcome".
Results From the starting 312 papers available, 20 manuscripts were finally included. Only one included study has a control group. The main indication for metal cones is type IIb and III defects according AORI classification. Most of the papers show good clinical and radiological outcomes with low rate of complications.
Conclusion The examined studies provide encouraging clinical and radiological short-to-mid-term outcomes. Clinical studies have shown a low rate of aseptic loosening, intraoperative fractures, infection rate and a lower failure rate than the previous treatment methods. Higher quality papers are needed to draw definitive conclusions about porous metal cones.

Keywords Porous metal cones · Knee revision · Bone loss · Knee arthroplasty · Periprosthetic joint infection · Outcome

Introduction

Nowadays, total knee arthroplasty (TKA) is one of the most widely performed procedures in orthopaedics practice, since it has shown to provide excellent outcomes, relieving pain, and restoring joint function.

The number of revision total knee arthroplasties (rTKA) in the United States was projected to grow by 601% between 2005 and 2030 [1]. RTKA still represents a diagnostic and therapeutic challenge for the orthopaedic community worldwide [2, 3]. The results after primary TKA are reasonably predictable and reproducible, while rTKA is usually associated with worse outcomes [4]. Ideally, there is some goals to achieve approaching knee revision surgery: accurate mechanical alignment, durable fixation, and ultimately, an infection free, well-balanced, mobile, and painless knee [5].

Total knee arthroplasty failures can be caused by different reasons. Among these, the assessment of remaining bone stock is crucial to achieve a successful implant. Bone loss can jeopardize the correct positioning and alignment of the prosthetic components, and can limit the achievement of a stable bone–implant interface. Engh et al. [6, 7] proposed the classification of the knee bone defects according to the "Anderson Orthopaedic Research Institute" (AORI). The AORI classification is commonly used to describe femoral and tibial bone loss in rTKA as follows: Type 1: intact cortical bone with minor cancellous bone defects (cystic lesions) which will not compromise the stability of a revision prosthetic component; Type 2: damaged cortical bone with loss of cancellous bone in the metaphyseal segment that will need to be filled to restore the joint line. Type 2A defect involves one condyle or hemi-plateau (F2A or T2A). In Type 2B, bone loss involves both femoral condyles and/or the entire tibial plateau (T2B or F2B); Type 3 is a major

✉ Stefano Divano
ste.divano@hotmail.com

1 U.O. Clinica Ortopedica e Traumatologica, Ospedale Policlinico San Martino IST, largo R. Benzi 10, 16132 Genoa, GE, Italy

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deficiency in metaphyseal bone, i.e., bone loss that comprises a major portion either one or both femoral condyles (3F A/B), or one or both sides of the tibial plateau (3T A/B). These defects are often associated with detachment of the collateral or patellar ligaments. The variability in size and location of bone defects has led to the development of a multitude of techniques aimed at restoring physical integrity of the knee and supporting prosthetic replacement. The optimal therapeutic approach to severe bone loss following TKA has not been established yet [6]. For smaller defects morselized cancellous allograft, cement and screws or porous metal augment can be enough. For larger defects, structural allografts and porous metal devices have a starring role, since the concept of zonal fixation was postulated by Morgan-Jones [8]. Metaphyseal tantalum cones and porous sleeves are largely recommended for bone defects type 2b and type 3, since they provided good short/mid-term outcomes. Finally, custom-made prostheses or mega implants have been suggested for uncontained extra-articular bone loss. Pour et al. [9] have shown a 5-year survivorship of 68% using tumor-type megaprostheses for reconstructions of severe bone defects during a rTKA.

The body of the literature and interest surrounding metal cones is still growing but few systematic evaluations of the existing evidence have been performed. The aim of our systematic review is to collect and critically analyze the available evidence about porous metal cones in revision knee arthroplasty especially focusing our attention on indications, results, complications, and infection rate of these promising orthopaedic devices.

Materials and methods

We performed a systematic review of the available English literature to analyze indications, results, and complications of porous metal cones as potential treatment to manage bone loss within revision TKA. The primary search was performed on Medline through PubMed using the following strategy: ((revision[All Fields] AND ("arthroplasty, replacement, knee" [MeSH Terms] OR ("arthroplasty" [All Fields] AND "replacement" [All Fields] AND "knee" [All Fields]) OR "knee replacement arthroplasty" [All Fields] OR ("knee" [All Fields] AND "arthroplasty" [All Fields]) OR "knee arthroplasty" [All Fields])) AND ("arthroplasty, replacement, knee" [MeSH Terms] OR ("arthroplasty" [All Fields] AND "replacement" [All Fields] AND "knee" [All Fields]) OR "knee replacement arthroplasty" [All Fields] OR ("knee" [All Fields] AND "replacement" [All Fields]) OR "knee replacement" [All Fields])) AND ("bone diseases, metabolic" [MeSH Terms] OR ("bone" [All Fields] AND "diseases" [All Fields] AND "metabolic" [All Fields]) OR "metabolic bone diseases" [All Fields] OR ("bone" [All Fields] AND "loss" [All Fields]) OR "bone loss" [All Fields]).

The inclusion criteria were: studies providing clinical and radiological results about metaphyseal tantalum cones in rTKA, papers in English without any restrictions on publication date, retrospective or prospective studies including randomized controlled trials, nonrandomized trials, cohort studies, case–control studies, and case series studies with minimum mean follow-up (FU) of 6 months. Non-pertinent manuscripts were excluded. The criteria for exclusion were: articles which did not provide clear clinical and radiological results of porous metal cones in rTKA or papers not related to the research item, case report and review or meta-analysis. We carefully examined reference lists from previous reviews or meta-analysis in order not to miss pertinent papers. Two reviewers (L.C. and S.D.) independently applied the previously determined inclusion and exclusion criteria to select potentially relevant papers. Papers were initially identified based on title and abstract. Full text copies of relevant trials were then obtained and independently evaluated by the reviewers. When a disagreement between reviewers occurred, it was resolved by a meeting held in consultation with another author. References from the identified articles were checked in order not to miss any relevant articles. The following data were extracted from the articles: level of evidence (LOE), number of patients/implants/cones, level of constraint of implants, preoperative diagnosis, method of fixation, mean follow-up, drop-out rate, intraoperative fracture rate, aseptic loosening (AL) rate, infection rate, reoperation rate, and revision rate. We considered reoperation as any further surgery after cones implant and revision as surgery with need of prosthetic implant removal. The LOE of a given study was assigned based on the 2011 Oxford Centre for Evidence-based Medicine Levels of Evidence [10]. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2009 checklist was considered to edit our review. Continuous variables were reported as mean ± standard deviations (SD). Categorical variables were expressed as number of cases or percentage.

Results

Following the research protocol, a total of 312 articles were identified. The PRISMA flow 2009 diagram illustrates the number of studies that have been identified, included, and excluded as well as the reason for exclusion (Fig. 1). A total of 20 articles were included in our systematic review. The first paper included was published in 2006, the last one in 2017. Due to the heterogeneity and low quality of the included studies, it was impossible to pool and standardize the demographic and surgical data from the entire population and each group. Table 1 summarizes demographic data

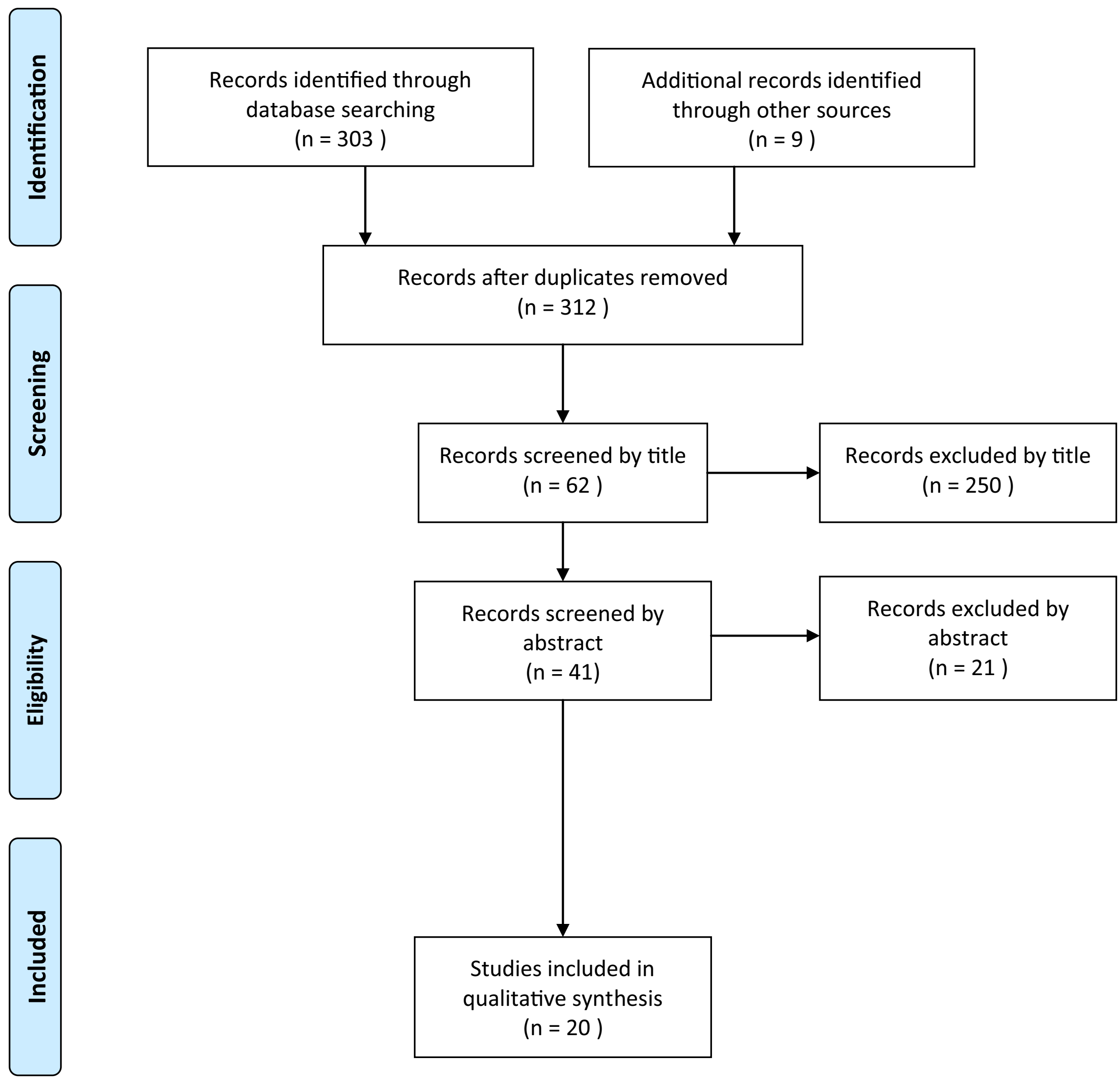

Fig. 1 The PRISMA flow 2009 diagram which illustrates the number of studies that have been identified, included, and excluded as well as the reason for exclusion

of the included studies. Most of studies were rated as level IV (retrospective non-controlled studies) according to the 2011 Oxford Centre for Evidence-based Medicine Levels of Evidence, just one paper was rated level III (cohort study) [11].

Demographics

Pooling the available data from the included studies, 788 patients with a mean age of 68.28 ± 3.48 underwent rTKA with metal cones. Only four studies achieved a relevant (> 50) number of patients [24, 27, 28, 30]. 766 prostheses were implanted: 381 varus–valgus constraint (VVC), 77 posterior stabilized (PS), 250 hinged prostheses, 4 cruciate retaining (CR), 18 rotational knee prostheses (RKP), 1 megaprosthesis, and 16 unspecified implants. 812 cones were implanted with a mean survival rate of 94.55% and a mean follow-up of 3.65 ± 1.97 years. All studies stated the reason for revision surgery. A total of 340 (44.4%) cases of aseptic loosening (AL) were observed. Periprosthetic joint infection (PJI) is the second common cause of revision (243 patients), followed by instability (62 patients). Other preoperative diagnosis included: 16 periprosthetic fractures (PPF), 2 acute fractures, 53 osteolysis, 3 pain, 13 stiffness, 2 malalignment, 1 traumatic arthrotomy, 17 implant failures, 2 abnormal extensor mechanism and 1 poly-wear, 2 fractures of tibial component, 13 stiffness, 3 malrotations, 4 primary, 1 breakage of megaprosthesis tibial component, 1 other. Some studies reported more than one preoperative diagnosis for each patient. Most of studies included patients

Table 1 Summarizes demographic data of the included studies

Author	LOE	No patients/knees/cones	Mean age (years)	Preoperative diagnosis	Bone defect classification	No cones (F/T/FT)	Method of fixation	Final knee prosthesis	Mean follow-up (years)	Drop-out rate %
Radnay and Scuderi [12]	IV	Nove/dieci/dodici	Not declared	8 AL; 1 PJI	AORI (T2, T3, F2, F3)	2/10/2	4 cementless, 6 cemented	Not declared	0.9	0
Meneghini et al. [13]	IV	15/15/15	68.1	5 PJI; 4 AL; 3 osteolysis; 2 PPF; 1 instability	AORI (7 T2B, 8 T3)	0/15/0	3 cementless, 12 cemented	7 hinged; 2 CC; 6 PS	2.8	0
Long et al. [14]	IV	15/16/16	66	13 AL; 3 PJI	AORI (2 T2A, 3 T2B, 11 T3)	0/16/0	Cementless/cemented	16 CC	2.6	0
Howard et al. [15]	IV	24/24/24	64	11 AL; 7 PJI; 3 osteolysis; 2 PPF; 1 instability	AORI (F2B, F3)	24/0/0	Cemented	10 hinged; 11 CC; 3 PS	2.8	0
Lachiewicz et al. [16]	IV	27/27/33	64.6	10 AL; 13 PJI; 4 osteolysis	AORI (4 T2B, 20 T3, 9 F3)	3/18/6	21T cemented, 3T cementless, 4F cemented, 5F cementless	3 hinged; 17 CC; 5 PS; 2 CR	3.3	22.2
Rao et al. [17]	IV	26/26/29	72	14 AL; 9 PJI; 3 PPF; 2 osteolysis; 1 acute fracture	AORI (13 T2A, 4 T2B, 3 2FA, 8 T3, 1 F3)	5/25/3	Cementless	26 hinged	3	0
Villanueva-Martinez et al. [18]	IV	21/21/29	73	16 AL; 5 PJI	AORI (3 T2A, 3 T2B, 3 F2B, 5 T3, 14 F3)	10/3/8	Cementless/cemented	10 hinged; 11 CC	3	0
Schmitz et al. [19]	IV	44/44/60	72	38 AL	AORI (9 2A, 10 2B,19 3)	13/9/16	Not declared	18 rotational knee; 26 hinged	3.1	13.7
Fosco et al. [20]	IV	10/11/dodici	62	4 PJI, 5 AL, 1 malrotation, 1 breakage of megaprosthesistibial component	AORI(5 T2B, 1 T3, 5 F2B, 1 F3)	05/05/01	Cementless/cemented	7 CC, 2 RHK, 1 PS, 1 megaprosthesis	3.3	0
Derome et al. [21]	IV	29/29/33	Not declared	20 AL; 7 PJI; 2 PPF	AORI (T2B, T3; F2B; F3)	12/13/4	Cementless	18 CC; 11 PS	2.8	6.5
Mozella et al. [22]	IV	10/dieci/dodici	71	3PJI, 1AL, 3instability, 2 osteolysis, 1poly-wear	AORI (F2B, F3,T2A,T2B,T3)	3/9/2	Cemented	7CC, 3 hinged	2.9	10

Table 1 (continued)

Author	LOE	No patients/knees/cones	Mean age (years)	Preoperative diagnosis	Bone defect classification	No cones (F/T/FT)	Method of fixation	Final knee prosthesis	Mean follow-up (years)	Drop-out rate %
Jensen et al. [23]	IV	36/36/36	69	15 AL; 15 PJI; 5 instability; 1 pain	AORI (27 T2, 9 T3)	0/36/0	Cementless	16 hinged; 14 CC; 6 PS	3.9	38.9
Kamath et al. [24]	IV	63/66/66	Not declared	15 AL; 26 PJI; 10 osteolysis; 1 PPF; 2 fracture of tibial component; 12 instability	AORI (17 T2A, 25 T2B, 24 T3)	0/66/0	62 cemented, 4 cementless	25 hinged; 33 CC; 7 PS; 1 CR	5.8	20.6
Boureau et al. [25]	IV	Sette/sette/quattordici	65	4 AL; 3 PJI	AORI/SoFCOT (2 F2B/B, 5 F3/C)	14/0/0	Cemented	Not declared	1.4	0
De Martino et al. [26]	IV	18/18/26	73	5 AL; 13 PJI	AORI (3 T2B, 9 T3, 3 F2B, 10 F3)	6/5/7	15 cementless, 3 cemented	12 hinged; 6 CC	6	0
Brown et al. [27]	IV	83/83/94	69	30 AL; 21 PJI; 16 instability; 6 stiffness; 3 PPF; 2 malalignment; 1 traumatic arthrotomy; 4 primary	AORI (13 1; 28 2A, 47 2B, 6 3)	7/65/11	Cemented	11 hinged; 52 CC; 19 PS; 1 CR	3.3	0
Potter et al. [28]	IV	157/159/159	64	56 AL; 75 PJI; 26 osteolysis; 16 implant failure; 11 instability; 1 fracture	AORI (127 F2B, 32 F3)	159/0/0	Cemented	56 hinged; 96 CC; 7 PS	5	1.3
Girerd et al. [29]	IV	51/52/71	68	22 AL; 19 PJI; 1 instability; 2 abnormal extensor mechanism; 2 pain; 3 osteolysis; 1 implant failure; 1 stiffness; 1 other	AORI (2 T2A, 21 T2B, 15 T3, 10 F2B, 24 F3)	14/17/21	Cementless	38 hinged; 14 CC	2.8	0
Sandiford et al. [11]	III	45/14/15	71	37 AL; 2 PJI; 2 PPF	AORI (4 T2A, 2 T2B, 1 F2A, 7 F2B)	9/6/1	12cementless, 1cemented	45 CC	9	0

Table 1 (continued)

Author	LOE	No patients/knees/cones	Mean age (years)	Preoperative diagnosis	Bone defect classification	No cones (F/T/FT)	Method of fixation	Final knee prosthesis	Mean follow-up (years)	Drop-out rate %
Bohl et al. [30]	IV	98/98/56	69	16AL, 12PJI, 12 instability, 2 malrotation, 1 PPF, 6 stiffness	AORI (9 F1, 16 F2A, 21 F2B, 3 F3, 16 T1, 16 T2A, 16 T2B, 1 T3)	3/39/7	40 cementless, 9 cemented	12 PS, 32 CCK, 5 hinged	3.5	0
Total/mean	–	788/766/812	68.28	340AL, 243PJI, 53 osteolysis, 62 instability, 16PPF, 2 acute fracture, 1 poly-wear, 3 pain, 2 fracture of tibial component, 13 stiffness, 2 malalignment, 1 traumatic arthrotomy, 4 primary, 17 implant failure, 2 abnormal extensor mechanism, 3 malrotation, 1 breakage of megaprosthesis tibial component and 1other		289/357/89	–	381CC, 77PS, 250 hinged, 4CR, 18RKP, 1 megaprosthesis 16 unspecified	3.65	5.66
Dev std			3.48						1.97	10.57

with type 2b and type 3 bone defects according to AORI classification. Some papers are based on mixed cohort of patients above all according preoperative diagnosis, surgical techniques and method of fixation [11, 27, 31]. Some authors [13, 17] decided to fill any areas or voids between the periphery of the porous tantalum cone and the adjacent bone with morcellized cancellous bone graft or demineralized bone matrix, to prevent any egress of cement between the cone and the host bone during cementation of the components. The metaphyseal portions of the implants were cemented to the internal surface of the tantalum cones in all cases. The final components were then inserted through the cone with use of either cementless or cemented stem extension. Some authors decided to cement the entire length of the stem, on a case-by-case basis [13, 16]. Post-operative rehabilitation protocol, when specified, included unrestricted range of motion exercises and full weight bearing as tolerated, using crutches or a cane as necessary, beginning on the first post-operative day.

Results

Several clinical evaluation scales were used. Knee Society clinical scores (KSS) are the most widely evaluated parameter through the examinated papers. The other clinical scores evaluated are the Oxford Knee Score (OKS), Visual Analogue Score (VAS), The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Short Form-12 (SF-12) and the UCLA activity score. Some of the evaluated studies have a high drop-out rate [16, 23, 24]. Three of the included studies reported a survival rate lower than 90% at the last follow-up [14, 27, 28]. The average cones survival rate is 94.55%.

Complications

Only one of the included studies did not report any intra- or post-operative complication [25]. Average rate of reoperation is 16.19%. Average rate of revision is 8.19%. Average AL cones-related rate and average intraoperative fracture cones-related rate are 0.84 and 0.89%, respectively. The most frequently observed reason for reoperation and revision is PJI (59 and 40 patients, respectively). Table 2 summarizes these post-operative data. Average infection rate is 7.1%.

Discussion

The main aim of our systematic review is to evaluate the existing body of evidence of porous metal cones with a special focus on indications, results, complications, and infection rate. Our findings demonstrate that metaphyseal metal cones are a feasible and reliable option in bone loss management during rTKA. The improved osteointegration found with large porous metal augments resulted in improved outcomes [32]. Bobyn et al. [33] demonstrates 70–80% porous ingrowth by 52 weeks. Jensen et al. [34] publish a randomized radiostereometric study on rTKA tibial implants with or without the use of metal cones. They assess that revision tibial components with the use of metal cone show an early stable situation with less irregular migration pattern than revision without the porous cone, providing a beneficial effect for bone ingrowth and fixation of the metal cone. Porous metal devices share indications with structural allograft; for this reason, these two surgical techniques are often compared. Both techniques show pros and cons. Structural allografts have the theoretical advantages of biologic ingrowth and potential for bone stock restoration [35]. However, there are potential disadvantages as the technical difficulties, the risk of disease transmission, fracture of the graft, nonunion, and late resorption and collapse. Moreover long-term results are not so encouraging [36]. The porous metal metaphyseal cones show potential advantages such as easy to use surgical technique, high modularity, and early mechanical support without the risk of late resorption and collapse. Nevertheless Villanueva-Martinez et al. [18] underline some technical drawbacks for this system. First, there is the need to remove more bone to allow the cone to adapt to the residual anatomy of the patient. Second, the technique may eventually require a cone's reshaping to optimize the reconstruction placing the joint line in the proper position. Fortunately, the newer cones implement the number of sizes and shapes to accommodate most large defects and to minimize further bone loss from preparation. Moreover, newer cone systems allow bone preparation by utilizing power reaming over a canal reamer, avoiding a freehand preparation, which minimize fracture and malalignment risk. These results seem to be supported by the very low rate (0.89%) of intraoperative fracture. Nowadays, the decision about stem fixation method is still a preference based surgeon's choice. Some authors assume that a metaphyseal cementation over the tantalum cone combined with a long press fit stem can be sufficient to achieve a satisfying stability, even if no failures due to cement implant failure have been reported in rTKA with the use metal cones [23]. On the contrary, porous metal cones are often inserted with short or intermediate length cemented stems to ensure adequate initial stability needed for osteointegration. Once metaphyseal ingrowth occurs, the loads to the implant-host bone interface are dispersed away from the joint line. However, it is still unclear which method is preferable. Lachiewicz et al. [16] report no difference in the frequency of radiolucent lines around uncemented or cemented stem extensions. The authors find a very low AL cones-related rate 0.84%. Brown et al. [27] confirm these good results. The authors review 83 consecutive TKAs (79 revision, 4 complex primary) at

Table 2 Reports' complications rate, infection rate, revision, and reoperation rates of the included studies

Author	Rate intraop. fracture % (no cases/no implants)	Rate intraop. fracture cones preparation/insertion % (no cases/no implants)	Rate implant AL % (no cases/no implants)	Rate cones AL % (no cases/no cones)	Rate of infection % (no casi/no pz)	Rate of reoperation % (rate of rerevision)	Rate of revision % (rate of implant removal)	Cause of reoperation	Cause of revision	Other complications	Survival rate %
Radnay and Scuderi [20]	0	0	0	0	11	11	11	1 PJI	1 PJI	–	91.7
Meneghini et al. [13]	0	0	0	0	13.3	26.6	13.3	2 PJI, 1 PTF, 1 femoral AL	1 PTF, 1 femoral AL	–	93.4
Long et al. [14]	0	0	0	0	12.5	13	12.5	2 PJI	–	–	87.5
Howard et al. [15]	0	0	0	0	0	20.8	0	2 PPFF; 1 flexion instability; 1 synovial hyperplasia; 1 estensor mechanism disruption	–	1 PJI, 1 pes anserine bursitis	100
Lachiewicz et al. [16]	0	0	0	3.7	3.7	14.8	7.4	1 PFF, 1 wound dehiscence, 1PJI, 1 AL	1PJI, 1 AL	1 nonfatal perioperative myocardial infarction-and atrial fibrillation,1 nonfatal pulmonary embolus, 1 non-traumatic rupture of the vastus medialis obliquus	91
Rao et al. [17]	0	0	0	0	7.7	3.8	3.8	1 PJI	1 PJI	1 carcinoma of the oesophagus, 1 PFF, 2 shin pain	96.6

Table 2 (continued)

Author	Rate intraop. fracture % (no cases/no implants)	Rate intraop. fracture cones preparation/insertion % (no cases/no implants)	Rate implant AL % (no cases/no implants)	Rate cones AL % (no cases/no cones)	Rate of infection % (no casi/no pz)	Rate of reoperation % (rate of rerevision)	Rate of revision % (rate of implant removal)	Cause of reoperation	Cause of revision	Other complications	Survival rate %
Villanueva-Martinez et al. [18]	28.6	14.3	4.8	0	9.5	9.6	4.8	2 PJI	1 PJI	3 patellar tendon avulsion	93.1
Schmitz et al. [19]	0	0	5.3	2.7	0	5	5.3	2 AL	–	–	94.7
Fosco et al. [20]	9	0	0	0	0	0	0	–	–	1 delayed union of TTO, 1 intraoperative medial femoral condyle fracture	100
Derome et al. [21]	3.4	3.4	3.4	0	6.8	20.4	6.8	3 PJI, 1 wound breakdown, 1 patellar tendon avulsion, 1 AL	1 PJI, 1 AL	–	97
Mozella et al. [22]	0	0	0	0	10	60	20	1 hematoma drainage, 1 extensor mechanism rupture, 2 PF, 1 PJI, 1 instability	1 PJI, 1 instability	1 patella subluxation	100
Jensen et al. [23]	0	0	2.6	0	5.2	10	10.4	2 PJI, 1 AL, 1 instability	2 PJI, 1 AL, 1 instability	–	97

Table 2 (continued)

Author	Rate intraop. fracture % (no cases/no implants)	Rate intraop. fracture cones preparation/insertion % (no cases/no implants)	Rate implant AL % (no cases/no implants)	Rate cones AL % (no cases/no cones)	Rate of infection % (no casi/no pz)	Rate of reoperation % (rate of rerevision)	Rate of revision % (rate of implant removal)	Cause of reoperation	Cause of revision	Other complications	Survival rate %
Kamath et al. [24]	0	0	3	0	10.6	35	15.9	2 femoral fractures,1 tibial fracture, 5 extensor mechanism ruptures, 2 stiffness, 1 hematoma evacuation, 5 PJI, 2 AL, 3 cone explantations, 1 PF	4 PJI, 2 AL, 3 cone explantations, 1 PF	–	95.5
Boureau et al. [25]	0	0	0	0	0	0	0	–	–	–	100
De Martino et al. [26]	0	0	0	0	11.1	11	11.1	2 PJI	2 PJI	–	92.3
Brown et al. [27]	1.2	0	1.2	0	13.2	22.8	12	3 adhesions, 1 PTF, 1 instability, 9 PJI, 2 extensor mechanism failures, 1 traumatic arthrotomy, 1 AL, 1 PF	8 PJI, 1 AL, 1 PF	14 adhesions, 2 tibial fractures, 1 PTF, 1 wound infection, 1 intraoperative femur fracture	89.4
Potter et al. [28]	0	0	2.5	3.8	13.4	29	14.6	21 PJI, 10 AL, 7 instability, 3 traumatic fractures, 3 extensor mechanism disruptions, 1 flexion contracture	14 PJI, 6 AL, 3 instability	2 polyethylene dissociations, 2 wound complications	85.5

Table 2 (continued)

Author	Rate intraop. fracture % (no cases/no implants)	Rate intraop. fracture cones preparation/insertion % (no cases/no implants)	Rate implant AL % (no cases/no implants)	Rate cones AL % (no cases/no cones)	Rate of infection % (no casi/no pz)	Rate of reoperation % (rate of rerevision)	Rate of revision % (rate of implant removal)	Cause of reoperation	Cause of revision	Other complications	Survival rate %
Girerd et al. [29]	0	0	0	0	7.8	10	7.8	1 patellar tendon rupture, 4 PJI	4 PJI	–	93
Sandiford et al. [11]	0	0	0	6.6	0	7	7.1	1 AL	1 AL	–	93.3
Bohl et al. [30]	0	0	0	0	6.1	14.3	0	3 adhesions, 3 PJI, 1 extensor mechanism rupture	–	11 stiffness, 3 PPF	100
Mean	2.11	0.89	1.14	0.84	7.10	16.19	8.19	–	–	–	94.55
Dev. std	6.5811	3.24755373	1.7792369	1.8477297	4.9804327	13.922979	5.7664090	–	–	–	4.3343

a mean follow-up of 40 months, where femoral or tibial cones are used. Despite the high complication rate (45%) observed in this specific population, only one cone is revised for AL and another one femoral cone is noted to be loosened 5 years post-operatively. The most frequent complications in this series are infection (13%) and stiffness (20%). 1 year later; Potter et al. [28] along with the surgeons-developers of tantalum cones publish the results obtained from the most important cohort of patients at a mean of 5 years follow-up. They evaluate the outcomes of 157 cases (159 cones) of rTKAs in which at least 1 metal femoral cone is used. The indication for the indexed procedure is a two-stage treatment for PJI in 75 cases. The reported 5-year survivorship is 96% for revision for AL and decrease to 84% when the end point is revision for any reason. Two other main findings stand out from this work. First, aseptic failure of the femoral cone is always observed in patients with hinged prosthesis and AORI type-3 bone defects; this could mean that different implants with particular shapes should be considered in this setting. Villanueva-Martinez et al. [18] claims that the degree of constraint could be a main prognostic factor in functional outcome reporting better results for hinged than for VVC designs. Second, the authors cannot find significant differences comparing the obtained survival rates between the entire cohort and the PJI cases. This is a real interesting data, because it derives from the most relevant cohort of porous cone used in septic revision setting even if the authors do not compare clinical or radiological results between these two cohorts. Only two authors analyze clinical results according to preoperative diagnosis. In 2008, Meneghini et al. [13] first show their results obtained from a cohort of patients. Five surgeries are a second stage reimplantation for deep infection. When considered according to the diagnosis, patients with aseptic knee revision achieve slightly better results in terms of average extension, flexion, preoperative and post-operative KSS. Villanueva-Martinez et al. [18] publish their results obtained from a cohort of 21 patients (29 cones) followed up for a mean of 3 years. Although the low number of patients, the novelty of this study relies on the comparison between patients with different previous implants (primary versus revision), diagnosis (AL versus PJI), cementing techniques (methaphyseal versus diaphyseal), and number of cones (tibial/femoral versus both sides). Even though better results are achieved in hinged knee prostheses, the presence of a previous primary implant is the only parameter statistically related to good/excellent results. They do not report difference, in terms of function and complications, between septic or aseptic revisions. Another conclusion we can draw is that there is no significant difference in terms of survival rate, clinical and radiological outcome between femoral and tibial cones. Pooling the available data, the reported an overall survival rate of 95% with an infection rate of 7.1%. These data are comparable or even better than the best available evidence regarding infection rate after rTKA [37] underlining that porous metal cones represent a safe and effective way for bone loss management also in PJI. Undoubtedly, this review has some limitations. First of all, it is based on low-level studies that may bias the final results. No comparative trials between different techniques for bone loss management are now available. This limitation does not allow to assess the gold standard technique in this surgical setting. The difference in results reports and the use of different evaluation scales impair our ability to pool and compare final outcomes. Finally, none of the authors divide between new infection and septic failures after PJI treatment.

Conclusion

The examined studies provide encouraging clinical and radiological short-to-mid-term outcomes. Clinical studies have shown a low rate of aseptic loosening, intraoperative fractures, infection rate with an optimal overall survival rate. Newer generation systems can provide a further advantage for this technique. In conclusion, we found porous metal cones to be a durable and reliable option in rTKA with type IIb and III AORI bone defects. Further comparative high-quality long-term studies are still needed to better clarify complications, clinical and radiological outcomes of each surgical technique.

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Compliance with ethical standards

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

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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