Indications and techniques for non-articulating spacers in massive bone loss following prosthetic knee joint infection: A scoping review

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Abstract

Introduction

Prosthetic joint infection (PJI) is a destructive complication of knee replacement surgery (KR). In two-stage revision a spacer is required to maintain limb length and alignment and provide a stable limb on which to mobilise. Spacers may be articulating or static with the gold standard spacer yet to be defined. The aims of this scoping review were to summarise the types of static spacer used to treat PJI after KR, their indications for use and early complication rates.

Methods

We conducted a scoping review based on the Joanna Briggs Institute's "JBI Manual for Evidence Synthesis" Scoping review reported following Preferred Reporting Items for Systematic Review and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist. MEDLINE, EMBASE and CINAHL were searched from 2005 ~~–~~to 2022 for studies on the use of static spacers for PJI after KR.

Results

41 studies (1230 patients/knees) were identified describing 42 static spacer constructs. Twenty-three (23/42 [54.2%]) incorporated cement augmented with metalwork, while nineteen (19/42, [45.9%]) were made of cement alone. Spacers were most frequently anchored in the diaphysis (22/42, [53.3%]), particularly in the setting of extensive bone loss (mean AORI Type = F3/T3; 11/15 studies 78.3% diaphyseal anchoring). 7.1% (79 of 1117 knees) of static spacers had a complication requiring further surgery prior to planned second stage with the most common complication being infection (86.1%).

Conclusions

This study has ~~summarized~~ summarised the large variety in static spacer constructs used for staged revision KR for PJI. Static spacers were associated with a high risk of complications and further work in this area is required to improve the quality of care in this vulnerable group.

Key words:

periprosthetic joint infection; revision knee replacement; two-stage revision; non-articulating spacer; bone loss; treatment failure

Introduction

Knee replacement (KR) surgery is one of the most commonly performed musculoskeletal procedures and is highly successful at improving pain and function in patients with end-stage osteoarthritis refractory to non-surgical management [1, 2]. ~~Whilst~~ However, rare, periprosthetic joint infection (PJI), which has an incidence of around 1%, is particularly destructive and associated with an increased risk of morbidity and mortality [3, 4]. A~~s the~~ number of KR and revision knee replacements (rKR) increase, so do the number of PJI cases which present an increasingly challenging problem [1, 5, 6].

The preferred method of PJI treatment in the majority of cases is surgical – other than exceptional circumstances when patients are too frail to undergo an operation. ~~Whilst~~ While there is an increase in the ~~utilization~~ utilisation of debridement, antibiotics and implant retention (DAIR) and one-stage revision, the two-stage revision is still considered the gold standard technique [7]. The decision to perform a two-stage revision is based on patient, disease and surgical factors. Two-stage revision is indicated in the setting of massive bone loss, compromised soft tissue envelope or the unstable knee, due to ligamentous instability or extensor mechanism insufficiency. Additionally, two-stage revision may be preferred where the infecting organism is difficult to treat, such as fungal PJI, or is resistant to first line antibiotics [8, 9].

In two-stage revision a spacer is required between the first and second stages to maintain limb length and alignment and provide a stable limb on which to mobilise. The gold standard spacer has yet to be defined but they may be articulating or static and permit the delivery of high concentration local antibiotics to reduce the risk of systemic antibiotic side effects [7, 10, 11]. Static spacers are indicated in the setting of massive bone loss, compromised soft tissue envelope and where there is concern about the function of the ligaments and/or extensor mechanism [12]. Static spacers are more likely to be used in multiply revised cases with resultant massive bone loss as the use of dynamic spacers may lead to instability of the joint [9].

A wide range of static spacers ranging from proprietary to custom-made devices have been reported in the literature [13–20]. This scoping review aims to review the different static spacer types that have been published in the literature. It will review the indications for use, techniques and complications observed in clinical practice. The results of the review will be used to inform clinical practice and provide guidance as patient populations that may benefit from more stable spacer constructs.

Materials & Methods

We conducted a review based on the Joanna Briggs Institute's "JBI Manual for Evidence Synthesis" and used the " PRISMA-ScR" checklist, an extension of the "Preferred Reporting Items for Systematic Review and Meta-Analyses" (PRISMA) for reporting [21, 22].

Study eligibility criteria

This review included randomised controlled trials, non-randomised controlled trials, before-after studies, and interrupted time -series studies, as well as prospective and retrospective cohort studies, case- -control studies, and analytical cross-sectional studies. Descriptive observational studies, including case series, single- -case reports, and descriptive cross-sectional studies, were also incorporated. To be eligible for inclusion in this review, published articles had to describe adults aged 18 years or older with a PJI who underwent revision surgery with a static spacer. Papers from peer-reviewed journals published between 2005 and 2022 were considered with no restrictions in language. The full inclusion and exclusion criteria are available in Table 1.

Search strategy

The following bibliographic databases were to identify potentially relevant documents: MEDLINE (1950 to present), EMBASE (1974 to present) and CINAHL (1982 to present). The initial MEDLINE search strategy was drafted by an experienced librarian and further modified by the reviewers. The MEDLINE search strategy ~~can be found~~is presented in Table 2.

The initial MEDLINE search strategy, including all identified keywords and index terms, was adapted for each included database and/or information source. The reference list of all included evidence sources was searched for additional studies. To capture primarily contemporary studies that report the use of more modern techniques, references published between 2005 and 2022 were considered. Studies published before 2005 were not considered, nor were systematic reviews and other reviews. However, they were checked for potentially relevant references.

Study selection

All references were thoroughly deduplicated before screening of titles and abstract. Using the Rayyan Systematic Review App [23], two independent, blinded reviewers screened the reference titles and abstracts using the previously defined search strategy (reported and conducted in line with the PRISMA-ScR statement) and identified potential studies. The reviewers then assessed the full-text manuscripts for eligibility, based on the pre-established inclusion and exclusion criteria. Any discrepancies after the full-text evaluation were discussed between the reviewers.

Data extraction

The ~~D~~data from all the included manuscripts were extracted and collected using a data extraction tool developed by the reviewers. The draft data extraction form was not modified during the data extraction process. Any disagreements between reviewers were resolved through discussion or with one or more additional reviewers. The draft extraction form ~~can be found~~is shown in Table 3.

Data were collected on the types of spacers used in the studies, including images of the spacer system when available, surgical technique, the population on which the studies were performed, the number of cases in the studies, Anderson Orthopaedic Research Institute classification of bone defects (AORI) types, the post-operative management (full or partial weight bearing, bracing) and information on any complications that occurred while the spacer was in situ.

Results

A total of 1902 references were identified through the database search with three further references identified in grey literature [24]. After removing all duplicates (n = 858) and studies published before 2005 (n = 81), a total of 966 remaining titles and abstracts were screened. 771 references were excluded in the initial screening process. 195 references were considered potentially relevant and were therefore screened for full text. After the full-text screening, another 154 references were excluded, and 41 references that met the inclusion criteria were included. The 154 excluded studies dealt with dynamic spacers, contained little or no information on the spacer systems used, had an inappropriate study population or had only the title/abstract available. Figure 1 shows a PRISMA flowchart illustrating the results of the literature search and review in detail. (Fig. 1 PRISMA Flowchart)

Characteristics of the Studies reporting static spacer use for PJI

The 41 included studies [16, 19, 20, 25–62] included a total of 1,230 knees with a median of 20 (range 1~~–~~–133) knees per study. Twenty-one studies were from Europe (51.2%), 13 studies were from the United States (31.7%)~~,~~ and seven studies were from Asia (17.1%). Of the 41 included studies, the majority [n=23] (53.7 %) were published between the years 2015~~–~~–2022. Thirteen studies (36.6%) were published between the years 2010 and 2015, and the other four studies (9.8%) were published between the years 2005 and 2010. (Table 4 Results)

Spacer types, Spacer fixation and Weight bearing status

Figure 2 shows a flowchart illustrating the results on spacer types, spacer fixation and weight bearing status. (Fig. 2 Results)

Antibiotic therapy

Antibiotic bone cement was used in all studies. In all but ~~Seven~~ seven studies (17%) the antibiotics used were specified. Six studies (14%) used antibiotic monotherapy, while ~~Twenty~~twenty-nine studies (69%) used dual antibiotic therapy. The most commonly used antibiotics were ~~Vancomycin~~

vancomycin used in ~~Twenty~~twenty-eight studies (77%), ~~Gentamycin~~ gentamycin used in ~~S~~sixteen studies (38%) and ~~T~~tobramycin used in ~~T~~thirteen (31%) of the studies.

Complications

Twenty-nine studies (70.7%, 1117 knees (90.8%)) reported information related to complications related to the spacer or occurring when the spacer was in situ. Of those that reported complications, twelve (41.4%, 294 knees (26.3%)) reported that no complications occurred during or after their treatment, whereas sixteen (55.2%, 723 knees (64.7%) reported complications.

Of the 1117 knees where data were available, 229 complications (20%) were reported out of which 169 (73.8%) were infections and 60 (26.2%) were of non-infectious cause.

17 of the 60 (28.3%) non-infectious complications were described as spacer-related complications. These included three spacer dislocations (3/17, [17.65%]), nine tibia fractures (9/17, [52.94%]), three femur fractures (3/17, [17.65%]), one peri-spacer fracture not further described (1/17, [5.88%]) and one spacer fracture (1/17, [5.88%]).

Further, 7 of the 60 (11.7%) described non-infectious complications were implant-related complications, including two periprosthetic fractures (2/7, [28.6%]) and five cases of aseptic loosening (5/7, [71.4%]).

Soft tissue ~~C~~complications accounted for 19 of the 60 (31.7%) non-infectious complications and included five cases of wound healing disorders (5/19, [26.3%]), twelve case s described in which the soft tissue condition of the patients required flap coverage (12/19, [63.2%]) and two cases in which the peroneal nerve was affected (2/19, [10.5%]).

13 of the 60 (21.7%) non-infectious complications were described as functional complications. Five cases of extensor lag were described (5/13, [38.5%]), one case of patellar instability (1/13, [7.7%]), one case requiring patellectomy (1/13, [7.7%]) and three cases were described as requiring mobilisation (3/13, [23.1%]). Three patients were also reported to have extensor mechanism disruption (3/13, [23.1%]) and two were reported to have tibial bone loss (2/13, [15.4%]).

Deep vein thrombosis (1/2, [50%]) and respiratory complication (1/2, [50%]) were the remaining 2 of the 60 (3.3%) non-infectious complications described.

Overall, 96 complications (41.9%) occurred while the spacer was in situ. The most common complication associated with the spacer in situ was persistent infection, occurring in 73 cases (76%). Another 23 complications (24%) were of non-infectious origin.

Out of the 73 cases of persistent infection, spacer exchange was performed in 32 (43.8%) cases, while arthrodesis was performed in another 32 (43.8%). 4 cases (5.5%) were treated by ~~I~~irrigation and debridement and the remaining 5 cases (6.9%) had unspecified treatment approaches.

Regarding non-infectious complications while the spacer was in situ, 17 of the 23 events (73.9%) were directly related to the spacer. Amerstorfer et al. [25] reported on spacer dislocations (2/23, [8.7%]) and one case (1/23, [4.3%]) of a fractured spacer. Similarly, Llado et al. [48] documented one instance of spacer dislocation (1/23, [4.3%]). Faschingbauer et al. [34] reported nine tibia fractures (9/23, [39.1%]), three femur fractures (3/23, [13%]) and one fractured spacer (1/23, [4.3%]).

The remaining 6 of the 23 complications (26.1%) were three cases of wound healing disorders (3/23, [13%]), one respiratory complication (1/23, [4.3%]) reported by Cabo et al. [30] and two neurological complications (2/23, [8.7%]) reported by Faschingbauer et al. [34].

AORI Types/Bone Stock

Twenty-four studies (65.1%) contained no information concerning the AORI types or the bone stock of the cases they described. There were eight studies (22.4%) with a total of 275 cases that provided information on the AORI type of the patients. The mean AORI Type on the Femur and Tibia was F3/T3 (significant cancellous metaphyseal bone loss compromising the ligamentous instability of a major portion of the tibial or femoral condyle, association with patellar tendon detachment). Nine studies (12.5%) with a total of 154 cases that provided descriptive information on the bone condition.

Several studies reported that where there was evidence of bone loss [25], AORI 2b or greater [39], AORI 3 or ligamentous instability [19, 28], cement augmented with intramedullary device (rod or nail) was used to ensure adequate mechanical stability. Of a total of 212 cases in which information on massive bone defects/loss was provided by means of AORI classification, 207 (97.6%) were fixated on the level of the diaphysis.

Discussion

Overall 41 studies describing 42 spacer constructs were identified. The re was a high degree of variability in the constructs used. The majority of constructs consisted of cement augmented with metalwork and were anchored in the diaphysis with patients most commonly made partial weight bearing post-operatively. The complication rate was 20.5%, with the most common complication requiring surgical intervention being infection.

TKR revisions due to PJI are complex procedures and there is a high risk of morbidity and mortality. Those knees that require static spacers likely represent those with more extensive pathology and it is striking that this study identified that 73 knees with spacer in situ (7%) needed to be revised prior to planned second stage due to persistent infection when in general systematic reviews have reported a success rate, ~~as~~ defined as being infection free at two years, of two-stage revision being between 80 and 90% [5, 63].

This study identified a complication rate of 20.5% associated with the use of static spacers, and as such it remains important to define the gold standard spacer for this vulnerable population. Persistent infection requiring exchange of the spacer prior to planned second stage was the most common complication observed in 11% of cases. How best to reduce this risk remains unclear, and likely a~~n~~ multi-factorial approach is required. ~~Whilst~~ While all studies reported the use of antimicrobial cement in their spacer construct to try to reduce the risk of persistent infection, it is unclear whether, or to what degree, the antimicrobial properties of the spacer influence the risk of recurrence of infection, or whether this is driven predominantly by pathogen and host factors and surgical factors, such as thoroughness of joint debridement. Nonetheless optimising the chemical and materials properties of spacers to reduce the risk of biofilm and optimise delivery of local therapies remains an area of active research that may hold further benefits.

The other important role of the spacer is to maintain limb length, alignment and stability, which from the patient perspective would be a spacer that permits full mobility without the need for assistive devices. This study found huge variability in the way that stability was achieved with different approaches to spacer fixation, spacer architecture and materials used. Diaphyseal anchorage was more commonly used in cases with greater bone loss, and theoretically this would be expected to give greater stability to the limb, but at the risk of seeding infection from the joint [39]. Furthermore, instrumentation of the diaphysis may result in an increased risk of fat embolism and systemic inflammatory response as seen during intramedullary nailing for trauma [64, 65]. When diaphyseal fixation was used, the cement spacer was typically augmented with metalwork. The metalwork used varied both in terms of length diameter and material used. Some spacers used multiple, small-diameter~~s~~ (3mm) short constructs, whereas other studies reported on the use of single, large-diameter (12mm), long (360~~-~~380mm) constructs spanning the lengths of both the tibia and femur. The materials used ranged from stainless steel to titanium to carbon fibre.
Overall, the risk of mechanical failure across the included studies was 0.4%. ~~Whilst~~ While little detail was given on the exact mechanism of failure, it is known that mechanical failure, and fracture, of intramedullary nails is associated with a high degree of bending moment and it is likely that diaphyseal fixed spacers are exposed to similar forces, all be it with longer lever arms [66]. In several biomechanical model analyses of implants used for trauma, significant effects of intramedullary nail diameter on bending~~,~~ and overall stiffness of the construct were observed. Clinical studies have also demonstrated that nails with a diameter of more than 10 mm have a significantly lower risk of fracture [67]. Thus, theoretically, a larger-diameter nail for use in a knee spacer may be associated with a lower risk of failure.

The use of a stable spacer construct has several advantages. Firstly, early post-operative weight bearing could potentially be permitted with more confidence, as it is often concerned about fixation stability that lead to post-operative restrictive instructions with weight bearing limitations. Previous

published studies have shown that early weight- bearing after surgical procedures in which fractures were fixed with intramedullary nails improved patient outcomes [68]. Trauma studies have demonstrated that immediate post-operative weight bearing significantly reduces morbidity and mortality and is associated with a lower complication rate, shorter length of stay and higher likelihood of discharge home, ; with no increased risk of implant failure [69, 70]. Secondly a more stable construct will likely help ~~soft~~ the soft tissue envelope heal, and anecdotally this has been our experience with the use of an arthrodesis nail at our institution. Whether full weight bearing is safe for patients with diaphyseally anchored spacers and what impact it has on quality of life, morbidity and mortality remains to be determined.

Despite this study being a comprehensive, systematic, review of the literature, it has several limitations. Firstly, due to the heterogenicity of studies in terms of patients, surgeons and spacers , we were unable to present qualitative data comparing outcomes of different types of spacers. Secondly, at present, the core outcomes for this patient population ~~has~~ have yet to be defined and as such reporting was highly variable across the literature. To further our understanding of this area for future studies, it is important that, in addition to a description of the spacer, a description of the indication for the spacer is provided outlining the degree of bone loss and other factors that influence the type of spacer used.

Our institution is a tertiary referral centre with a specialist interest in PJI, and as a consequence, our patient cohort is skewed towards more advanced disease, and those with more extensive bone loss and soft tissue involvement. In the setting of minimal bone loss, healthy ligaments and a healthy soft tissue envelope, our preference is to use a dynamic spacer. In patients undergoing two- -stage revision who require muscle flap for skin coverage, extensor mechanism reconstruction, or those with bone loss (AORI2 or higher), our preference is to use a 12- mm- -diameter intramedullary arthrodesis nail. Following removal of implants, debridement of bone and soft tissues, and radical

synovectomy, the limb is re-prepped and draped with re-scrubbing by the surgical team. The joint is prepared for insertion of the arthrodesis nail and antibiotic loaded calcium ~~sulfate~~ sulphate beads placed into the medullary canals. An arthrodesis nail is placed into the tibia and femur, the limb pulled out to length and screws placed to lock the nail. Bone wax is placed over the screw heads to prevent cement interdigitating with the drive. Antibiotic--loaded calcium ~~sulfate~~ sulphate beads are re-placed in the back of the joint and antibiotic--loaded cement is placed in the joint space and into the metaphysis but not deep into the diaphysis. Post-operatively the patient is placed in a cricket pad splint and allowed to partial weight bear.

This review has identified that there is high variability in the use of static spacers for two-stage revision surgery for PJI of the knee. We identified that 7.1% of patients with static spacers have a complication requiring further surgery before planned second stage and that infection was the most common complication. Diaphyseal anchored spacers were more commonly used in the setting of more extensive bone loss although there was no clear guidance in the literature on when diaphyseal anchoring of a spacer is required, or when cement spacers should be augmented with metal to improve stability. Patients undergoing two-stage revision with static spacers are at high risk of morbidity and mortality. Static spacers are associated with a high risk of complication and further work in this area is required to improve the quality of care in this vulnerable group.

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Legend Figures and tables

Table 1 Inclusion/Exclusion criteria

Inclusion	Exclusion
Randomised controlled trials, non-randomised controlled trials, before-after studies and interrupted time-series studies, prospective and retrospective cohort studies, case-control studies and analytical cross-sectional studies, case reports	Reviews, Meta-analyses, Editorials, Letters
Studies published between 2005 and 2022	Studies published before 2005
Age > 18	Age < 18
Studies describing a population that had revision for PJI	Studies describing a population that had revision for other causes
Studies in which a static spacers were used	Studies in which no static spacers were used
References in every language	No/poor information about the spacer available

Table 2 Ovid MEDLINE® Search strategy

1	Knee/ or Knee Joint/ or Knee Prosthesis/	79718
2	knee.mp.	186669
3	1 or 2	186669
4	Arthroplasty, Replacement, Knee/ or Prosthesis Failure/ or Knee Prosthesis/ or Prosthesis-Related Infections/ or Arthroplasty, Replacement, Knee/ or Replantation/ or Treatment Failure/ or Prosthesis Failure/ or Arthritis, Infectious/ or Joint Instability/ or Reoperation/ or Reoperation/ or Bone Cements/ or Polymethyl Methacrylate/ or Anti-Bacterial Agents/	597587
5	(PJI or Periprosthetic joint infection or Infection or Knee infection or One-stage revision or one-stage reimplantation or 1-stage revision or 1-stage reimplantation or two-Sstage revision or two-stage reimplantation or 2-stage revision or 2-stage reimplantation or one-stage exchange arthroplasty or 1-stage exchange arthroplasty or two-stage exchange arthroplasty or chronic periprosthetic joint infection or Massive bone loss or bone loss or failed revision arthroplasty or failed revision replacement or Arthroplasty or Total Knee Arthroplasty or Total knee replacement or TKA or TKR or TKA failure or TKR failure or septic loosening or aseptic loosening or Revision of total knee or Arthroplasty or Bone defects or Bony defects or Failed total knee arthroplasty or Revision total knee arthroplasty or Revision total knee replacement or septic revision total knee arthroplasty or revision total knee arthroplasties or complicated knee arthroplasty or periprosthetic knee infection reconstruction or primary total knee replacement or PJI Recurrence or knee replacement failing).mp.	1473921
6	4 or 5	1921378
7	Spacer*.mp.	43062
8	3 and 6 and 7	706

Table 3 Data extraction form draft

Author	Title	Country	Level of evidence	Spacer description	Image of the Spacer System	Case number	AORI/Bone Status	Complications	Weight-bearing ~~&~~ and Supportive aids

Fig. 1 PRISMA Flowchart

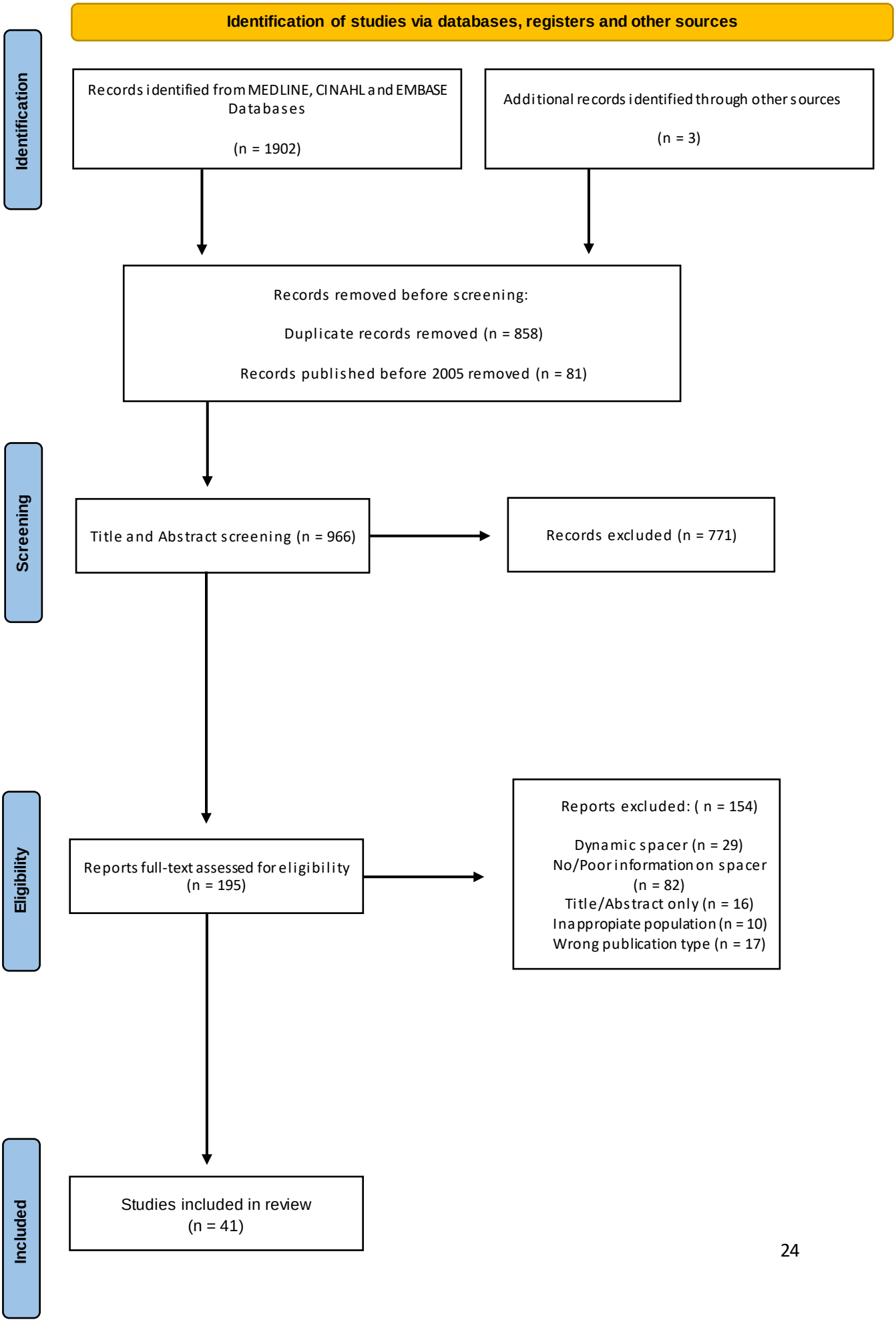

Table 4 Results table

Author	Country	Case number	Fixation Zone	Spacer type	Weight Bearing	Complications	AORI/Bone condition
Amerstorfer et al. (2021)	Austria	115	Epiphyseal Diaphyseal	Cement-Only (n = 96) Cement + IM Device (n = 19)	No information	Reinfection (n =24) Persistent infection (n = 7) Spacer dislocation (n = 2) Peri-spacer fracture (n = 1)	Type 1 (n = 7) Type 2 (n = 8) Type 3 (n = 4)
Anagnostakos et al. (2011)	Germany	3	Epiphyseal	Cement-Only	Partial weight bearing with support	No complications	No information
Antoci et al. (2009)	USA	1	Epiphyseal	Cement + IM Device	Partial weight bearing with support	No information	Bone destruction and massive bone loss
Antoci et al. (2009)	USA	9	Diaphyseal	Cement + IM Device	Partial weight bearing with support	No complications	Bone destruction and massive bone loss
Brunnekreef et al. (2013)	The Netherlands	9	Epiphyseal	Cement-Only	Full weight bearing without support	No complications	No information
Cabo et al. (2011)	Spain	25	Metaphyseal	Cement-Only	No information	Respiratory complication (n =1) WHD (n = 3)	No information
Chen et al. (2016)	Taiwan	8	Metaphyseal	Cement-Only	Full weight bearing without support	DVT (n = 1) Reinfection (n = 2)	No information
Chiang et al. (2011)	Taiwan	23	Epiphyseal	Cement-Only	No weight bearing allowed	Reinfection (n= 1)	Patients with major bone defects were excluded
Choi et al. (2012)	USA	33	Epiphyseal	Cement-Only	Weight bearing as tolerated without support	Reinfection (n = 11)	No information

Citak et al. (2011)	Germany	1	Epiphyseal	Cement-Only "The Distraction Spacer"	Full weight bearing without support	No complications	No information
Faschingbauer et al. (2016)	Germany	133	Diaphyseal	Cement + IM Device	Partial weight bearing without support	Arthrodesis following bone loss ~~&~~and persistent infection (n = 32) Tibia Fracture/Fissure (n = 9) Femur Fracture/Fissure (n = 3) Affected N. Peroneus (n = 2) Fractured Spacer (n = 1) Need for ~~mobilization~~ mobilisation (n = 3)	No information
Freeman et al. (2007)	USA	28	Epiphyseal	Cement-Only	Partial weight bearing without support	No information	No information
Gbejuade et al. (2016)	UK	1	Epiphyseal	Cement-Only	No information	No information	No information
Ghanem et al. (2016)	Germany	5	Diaphyseal	Cement + IM Device	No information	Reinfection (n =3)	No information
Hammerich et al. (2021)	Germany	110	Metaphyseal	Cement-Only „The Inverse Spacer"	Partial weight bearing with support	No complications	No information
Hipfl et al. (2019)	Germany	97	Diaphyseal	Cement + IM Device	Weight bearing as tolerated without support	Reinfection (n = 12) Persistent infection (n = 9) Aseptic loosening (n = 5) Extensor Mechanism disruption (n = 3)	2B or higher

						Periprosthetic fracture (n = 2) Patellar Instability (n = 1)	
Hsu et al. (2008)	Taiwan	31	Metaphyseal	Cement-Only	No weight bearing allowed	Reinfection (n = 4)	No information
Ippolito et al (2021)	USA	21	Diaphyseal	Cement + IM Device	No information	Persistent infection (n = 7) WHD (n = 2) Flap coverage necessary (n = 12) Extensor lag > 10 (n = 4) ~~Persistend~~ Persistent extensor lag without ~~identifyable~~ identifiable cause (n = 1) Tibial Bone loss (n = 2) Patellectomy necessary (n = 1) Reinfection (n = 2)	No information
Jaekel et al. (2012)	USA	14	Epiphyseal	Cement-Only	No information	No information	No information
Jeffery et al. 2013	UK	1	Epiphyseal	Cement-Only	No information	No information	No information

Johnson et al. (2012)	USA	65	Epiphyseal	Cement-Only	Partial weight bearing with support	Reinfection (n = 14)	Severe bone loss
Kellish et al. (2021)	USA	1	Diaphyseal	Cement + IM Device	No info	No complications	Massive bone loss
Kirschbaum et al. (2022)	Germany	87	Diaphyseal	Cement + IM Device	Full weight bearing without support	No complications	No information
Kotwal et al. (2011)	UK	58	Diaphyseal	Cement + IM Device	Weight bearing as tolerated with support	Reinfection (n = 6)	No information
Llado et al. (2016)	USA	1	Diaphyseal	Cement + IM Device	Partial weight bearing without support	Hardware Migration (n = 1)	Extensive bone loss
Preobrazhensky et al. (2019)	Russia	32	Diaphyseal	Cement + IM Device	Partial weight bearing with support	No information	< AORI 2B or 3 (n = 32)
Tahmasebi et al. (2020)	Iran	6	Epiphyseal	Cement-Only	Weight bearing as tolerated with support	No complications	No information
Nahhas et al. (2020)	USA	24	Diaphyseal	Cement + IM Device	Partial weight bearing with support	No information	No information
Nickinson et al. (2012)	UK	11	Diaphyseal	Cement + IM Device	Weight bearing as tolerated without support	Persistent infection (n = 1)	Significant bone loss
Park et al. (2010)	Korea	20	Epiphyseal	Cement-Only	Weight bearing as tolerated without support	Reinfection (n = 3)	No information
Pfitzner et al. (2015)	Germany	1	Diaphyseal	Cement + IM Device	Full weight bearing without support	No complications	F3/T3 (n = 1)
Lo Presti et al. (2021)	Italy	12	Diaphyseal	Cement + IM Device	Partial weight bearing with support	No complications	F3/T3 (n =11) F2b/T3 (n = 1)
Razii et al. (2020)	UK	9	Diaphyseal	Cement + IM Device	Partial weight bearing with support	No information	F3/T3 (n = 9)

				„The apple core spacer“			
Schrøder et al. (2012)	Denmark	5	Diaphyseal	Cement + IM Device	Partial weight bearing with support	No information	F3/T3 (n = 5)
Skwara et al. (2016)	Germany	21	Diaphyseal	Cement + IM Device	No information	No complications	Patients with massive bone loss were excluded
Supreeth et al. (2020)	Oman	4	Epiphyseal	Cement-Only	Partial weight bearing without support	No information	Type 1 (n =1) Type 2 (n =1) Type 2 (n =1) Type 3 (n =1)
Vasarhelyi et al. (2022)	UK	72	Diaphyseal	Cement + IM Device	Weight bearing as tolerated with support	No information	No information
Vielgut et al. (2021)	Austria	77	Epiphyseal	Cement-Only	No information	Reinfection (n = 14) Persistent infection (n = 17)	No information
Virk et al. (2020)	USA	30	Diaphyseal	Cement + IM Device	No information	No complications	No information
Yoo et al. (2011)	Korea	4	Diaphyseal	Cement + IM Device	Partial weight bearing without support	No complications	No information
Zielinski et al. (2019)	USA	22	Diaphyseal	Cement + IM Device	No information	No information	Substantial bone loss

Figure 1 Results