REVIEW

Nr 2023;13 (2):234-242

Knee Spacers in Periprosthetic Joint Infections: A Narrative Review

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DOI:
10.32098/mltj.02.2023.06

LEVEL OF EVIDENCE: 5

SUMMARY

Introduction. Periprosthetic joint infection (PJI) is a most common causes of failure of total knee arthroplasty. Knee spacers can be static or dynamic and are commonly used in the management of periprosthetic joint infection. Several types of spacers are available including rods, fixator rods, inverse spacers, handmade, molded, or preformed spacers with a cement-on-cement interface. This article provides a detailed review of knee spacers, their differences, and indications.

Materials and methods. In February 2023, PubMed, Embase, Scopus, and Google Scholar were accessed, with no time constraints.

Discussion. Spacers can be static or dynamic. Static spacers do not allow any movement, and should be used in patients with joint instability, insufficiency of the knee extensor mechanism, massive bone loss, and impaired wound healing with skin loss. On the other hand, dynamic spacers allow flexion and extension of the knee.

Conclusions. There is no evidence indicating the best choice when it comes to decide which articulating spacer to use.

KEY WORDS

Knee spacers; periprosthetic joint infection; dynamic spacer; static spacer; two-stage revision knee arthroplasty.

INTRODUCTION

One of the most common causes of failure of total knee arthroplasty (TKA) is periprosthetic joint infection (PJI) (1). PJI is associated with prolonged inpatient stay and high morbidity and mortality with its economic burden estimated to raise to $1,1 billion by 2030 (2). The diagnosis of PJI is based on a combination of clinical findings, laboratory results from peripheral blood and synovial fluid, microbiological culture, histological evaluation of periprosthetic tissue, and intraoperative findings (3). The criteria for the diagnosis of PJI are reported in the **table I**.

Periprosthetic joint infection can be early, delayed or chronic (4). Early PJIs are those occurring within 3 months after a TJR; PJIs with onset between 3 and 24 months are classified as delayed; late PJIs are those occurring over 24 months after a TJR (4). The management is surgical, and can be either one-stage or two-stage. Single-stage treatment became popular in 1985 through the work of Freeman *et al.* (5). This method had the advantage of reducing the number of surgeries, increasing the chances of maintaining motion and soft tissue health, and having lower costs (6). However, it had a low rate of success, which led to the implementation of the two-stage protocol (6). Two-stage revision knee arthroplasty was first described by Insall *et al.* in 1983 (7). Up to that time, PJI had been treated with intravenous antibiotics, arthrodesis, immobilization with a long leg cast, or amputation; by the end of the twentieth century, spacers were introduced in orthopedic practice (5). The idea of spacers first arose to avoid soft-tissue contracture, to reduce the discrepancy between the length of lower limbs and favor some mobility during the time in between prosthe-

Table I. Diagnosis PJI (3).

Diagnosis
Major criteria
Two positive cultures of the same organism
Sinus tract with evidence of communication to the joint or visualization of the prosthesis
Minor criteria
Preoperative diagnosis
Single positive culture
Serum ESR (mm/hr)
Serum CRP (mg/dL) or D-dimer (µg/mL)
Synovial Fluid WBC (cells/µL) or LE
Synovial Fluid Alpha defensin
Synovial Fluid CRP
Synovial Fluid PMN
Intraoperative fundings
Positive histopathology
Positive purulence
Positive molecular findings

sis reimplantation. The first studies on the use of spacers were conducted by Wilde and Ruth in 1988, and Booth and Lotcke in 1989; they reported, respectively, 90% and 96% success rate in eradication of infections (8, 9), the necessary step to proceed with the implantation of a new prothesis in the second stage. To verify clearance from infection, clinical signs of infection and blood cultures must be evaluated.
The main functions of spacers are still debated in literature and are summarized in **table II** (10).
Two types of spacers have been described, namely static and dynamic.

MATERIALS AND METHODS

Literature search

In February 2023 the following databases were accessed: PubMed, Embase, Scopus, Web of Science, Google Scholar. The following keywords were used in combination: Articulating spacer, Static spacer, periprosthetic joint infection, Dynamic spacers, revision TKA. If title and abstract matched the topic, the full text was accessed. The bibliographies of the full-text articles were also screened for inclusion. Disagreements were solved by a third senior author. According to the authors language capabilities, articles in English, French, German, Italian, and Spanish were considered.

STATIC SPACERS

Static spacers do not allow any kind of movement, keeping the joint either in extension or minimal flexion (11).
The main indications for the use of static spacers are (12, 13):
- Joint instability.
- Insufficiency of the extensor mechanism.
- Massive bone loss.
- Wound healing with skin loss.
- Patients with severe uncontrolled infections.

Different static spacers exist:
- Rods.
- Fixator rods.
- Inverse spacer.

RODS

Rods consist of a bar of different materials and sizes. Different types of rods are selected according to the anatomy of the patient encountered, such as Küntscher nails (7-9 mm in diameter and up to 30 cm in length), Steinmann pins (1.5-6.5 mm in diameter made of stainless steel), intramedullary nails, Rush rods (2-6 mm in diameter and up to 40 cm in length) (14, 15). Usually, the spacer is surrounded by antibiotic-loaded cement (16) (**figure 1**).

FIXATOR RODS

Fixator rods have diameters between 8.0 and 14 mm, according to the intramedullary diameter and the height of the patient (17). To guarantee a stable fixation of the rod to the tube connector, several attempts in flexion and exten-

Table II. Main functions of spacers (10).

Functions
Prevent shortening of soft tissue by maintaining tissue tension
Limit hematoma formation and/or proliferation of connective scar tissue and fat tissue
Stabilize joints to avoid dislocation by reducing empty space
Favour localized release of antibiotics
Avoid rigidity
Improve postoperative range of motion (ROM) and functional outcome (10)

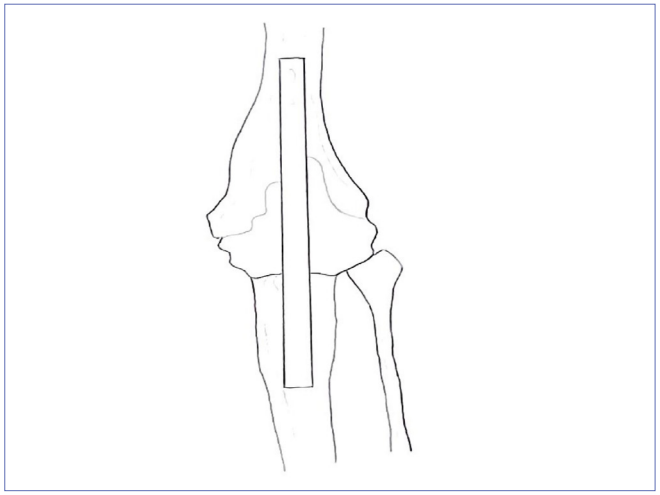

Figure 1. Rod.

sion positions are made until fixation in an extended position is reached. The nut of the connector is positioned medially so that it can be easily accessed when the spacer will be removed. The use of fixator rods allows patients to immediately regain full weight bearing, reducing bed rest complications (17) (**figure 2**).

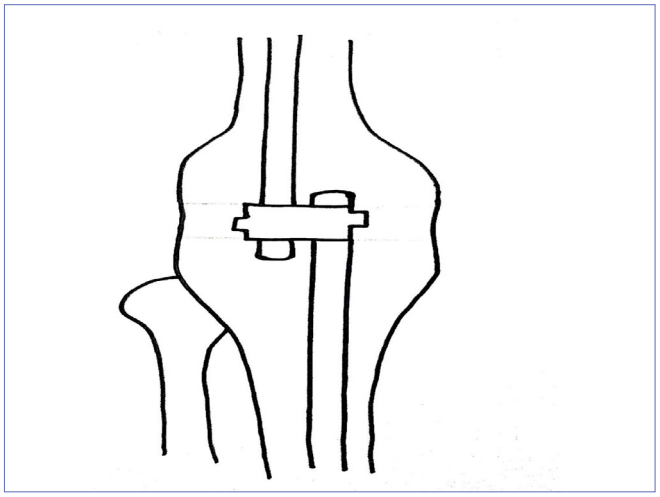

Figure 2. Fixator Rods.

THE INVERSE SPACER

The inverse spacer was designed as an articulating spacer but acts like a static one. The latter is made of independent tibial and femoral components (10). The tibial component is convex while the femoral one is concave. It is made with polymethyl methacrylate (PMMA) cement and intra-operatively shaped under maximum longitudinal tension at 5° flexion and 5° valgus position (10). Hammerich *et al.* suggested the use of a straight-leg brace with this spacer, rendering the spacer a static one (12). Eliminating anterior to posterior translation movements, inverse spacers reduce the range of motion of the resulting artificial "joint" acting as a pure hinge joint (10) (**figure 3**).

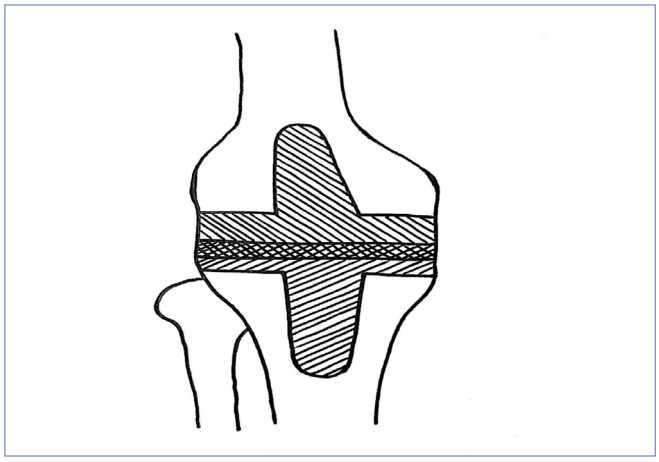

Figure 3. Inverse Spacer.

DYNAMIC OR ARTICULATING SPACER

Articulating spacers allow both flexion and extension of the knee, maintaining the joint space and local delivery of antibiotics, during the interval between surgical stages, and maintain adequate length and some motion of the extensor mechanism.

There are different types of articulating spacers:

- Handmade.
- Molded or preformed spacers with a cement-on-cement interface.
- Prostalac.
- Hoffman, made of metal on polyethylene.

HANDMADE

They are cement spacers without molds that vary in size and shape and are not commonly used (18). Different forms of spacer exist, including beads, balls, flattened blocks and intramedullary dowels/rods of polymethyl methacrylate; they may be constructed intraoperatively using antibiotic-impregnated cement (15). Handmade spacers enable specific tailoring to accommodate individual bone defects and anatomy of patients (19). These are formed around a Steinman pin, Kirschner-wire, or other such metal "endoskeleton", to mitigate the risk of fracture and other mechanical complications. In the knee, handmade spacers can also be constructed around arthrodesis intramedullary nails (19).

MOULDED OR PRE-FORMED SPACERS: CEMENT ON CEMENT INTERFACE

Molded or pre-formed spacers can be divided as follows.

Pre-molded

One type of pre-molded or pre-formed cement spacers are antibiotic spacers, with or without stems, that have non-interchangeable sizes of femoral and tibial components (20). The tibial component is not provided with a stem or an intra-articular post. They include trial of tibial and femoral components for intraoperative sizing (20). When these spacers are used, intramedullary antibiotic cement dowels for the distal femur and proximal tibia are prepared and inserted first, and then additional antibiotic bone cement is used to implant the pre-molded components to the distal femur and proximal tibia (20). A short amount of time needs to pass before engaging in weight bearing activities with one or two crutches to allow wound healing; however, active range of motion is encouraged (20) (**figure 4**).

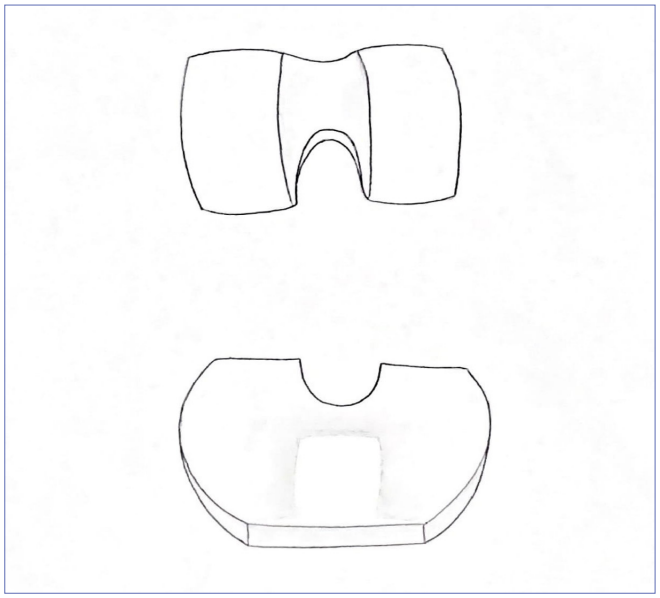

Figure 4. Premolded Spacer.

Surgical molds for intraoperative fabrication (with or without metal femoral runners)

Several types of surgical mold spacers are available. The non-metal molds for the tibia and femoral components are fabricated by the surgeon intraoperatively with the cement mixed with one or two antibiotics (21). Differently from pre-formed ones, the sizes of these molds are interchangeable (20). These cement-on-cement spacers are generally implanted with additional antibiotic bone cement and usually intramedullary dowels (20) (**figure 5**).

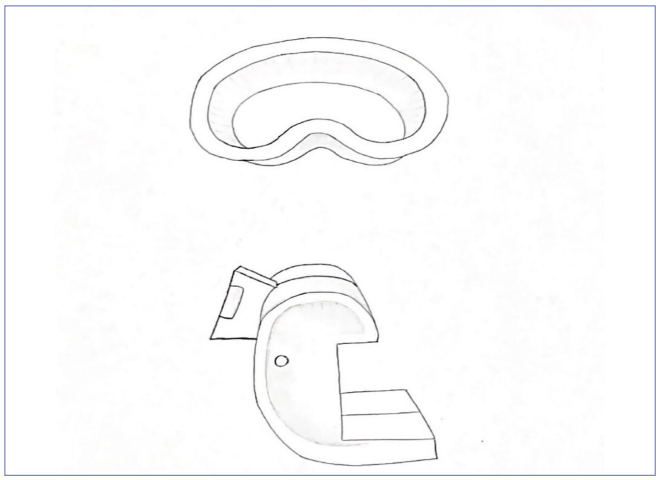

Figure 5. Surgical molds spacer.

PROSTHESIS OF ANTIBIOTIC-LOADED ACRYLIC (PROSTALAC)

First used in 1987, the PROSThesis of Antibiotic-LoadedAcrylic Cement (PROSTALAC) knee spacer consisted of a conventional handmade prosthesis made of antibiotic-loaded cement. In 1991, it was modified by using flexible polyethylene molds to produce smoother articular surfaces on the femoral and tibial components (22). The current PROSTALAC spacer, originally introduced in 1994, has femoral and tibial components both made of antibiotic loaded with acrylic cement; each component is cast in size specific molds (22). The tibial mold enables adjustment in the thickness of the spacer to assist restoration of bone loss and joint stability. It has a post-cam mechanism formed from cement, between two inlay polyethylene (PE) plateaus. The femoral component incorporates small metal runners linked together by a posterior cross bar to prevent posterior dislocation, thus producing a metal on polyethylene bearing (22) (**figure 6**).

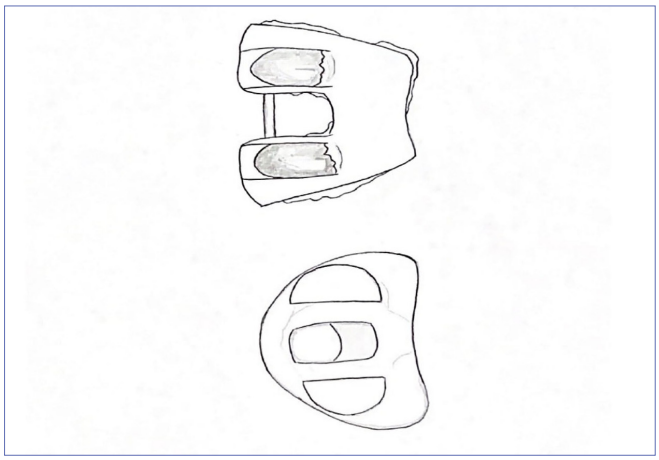

Figure 6. Prostalac.

HOFFMAN

In 1995, Hoffman *et al.* described a new dynamic spacer, made by cleaning and autoclaving the removed femoral component (6). The autoclave should be near the operating room to facilitate aseptic delivery to the sterile field.(23). If a spore test cannot be performed before implant use, the implant should undergo a full-cycle steam sterilization, not flash sterilization (24). During surgery, the femoral component is then reinserted and articulated with a new tibial polyethylene insert, as well as a new polyethylene patella component (6). Theoretically, the use of Hoffman spacer allows patients to achieve full eradication of the infection and satisfactory functional results, limiting the need for a second procedure to implant revision knee components (25) (**figure 7**).

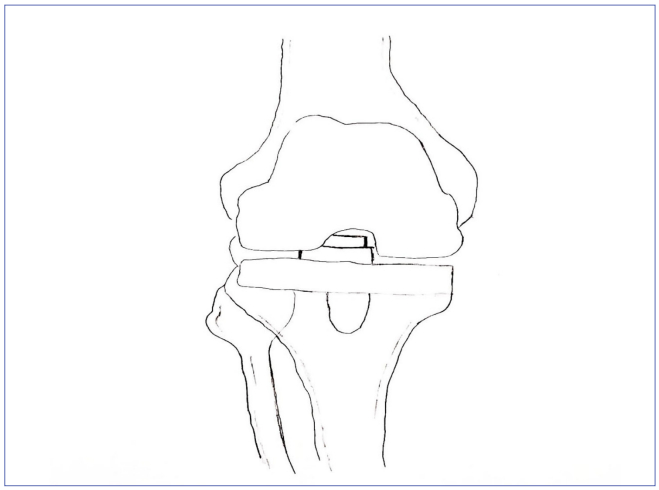

Figure 7. Hoffman.

DISCUSSION

Two-stage exchange arthroplasty with an antibiotic-impregnated cement spacer remains the standard treatment for patients with an infected total knee arthroplasty. Two-stage revision knee arthroplasty has an infection eradication rate between 83% and 91% (26, 27). In this review, we describe the different types of spacers. Static spacers do not allow any kind of movement, keeping the joint in extension and reducing the cost of surgery. The rate of complications following the use of static spacer is 11.2%, mainly tibia and femur fractures (28, 29). Llado *et al.* reported a case of migration of Steimann pins used for the management of PIJ (30). Among the causes of migration there are pin and wire size, smooth surface texture, broken or loose implants, osteolysis, poor bone quality, prolonged implantation time, repetitive movements across the line of axial motion of joints, gravitational forces, capillary actions, respiratory excursions, muscular activities, and traumatic dislodgements (30). Given their mechanical properties, fixator rods can be used in patients with large metaphyseal defects without the use of an external fixator (31). Moreover, they reduce the risk of complications, such as thrombosis or pneumonia, and are easier to remove in the second stage. However, they increase the risk of aseptic loosening, postoperative fracture and patellar instability as well as prolonging intraoperative time (17, 32). Inverse spacers reduce the risk of fracture and dislocations and the post-operative force/friction that occurs at the cement-spacer interface, avoid bone loss and are easy to remove at revision TKA (10). Periarticular bone loss is among the potential problems of static antibiotic-loaded spacer use (21). Calton *et al.* reported a 40% rate of tibial bone loss and a 44% rate of femoral bone loss in 25 patients treated with static spacers (33). Fehring *et al.* validated these results in a retrospective study comparing handmade cement articulating spacers with a static spacer block technique (34). Fifteen of 25 patients (60%) in the static spacer group experienced bone loss directly related to the spacer, with none identified in the articulating spacer group. Articulating spacers allow both flexion and extension of the knee (34). Maintaining the range of motion of the knee before implantation of the articulating spacer is important to restore stability in the tibial platform, the distal femoral cut, femoral and tibial canals, and preserve the gaps using the revision gap balancer (35). Delay in wound healing is reported when using articulating spacers (9). Handmade articulating spacers are less stable, and it is difficult to produce a well-shaped and congruent articular surface (36). Hand-made hip and knee spacers can be 40 to 50% cheaper than prefabricated spacers and spacer molds (37). In fact, the mean price for self-made knee spacer is 514 CHF (450 EUR/505 USD) for non-articulated and 535 CHF (470 EUR/525 USD) for articulated ones. For prefabricated knee spacers and knee molds spacers, the minimum cost is of 1050 CHF (922 EUR/1,030 USD) (37). This is a major economic advantage given the high costs of this surgical procedure (38). Pre-formed spacers have the disadvantage of being limited in size, hence they do not fit correctly in all patients (11). Prefabricated articulating cement implants have enhanced mechanical implant integrity when compared to intraoperatively molded spacers given the tightly controlled manufacturing process (39). Indeed, mechanical integrity of an intraoperatively molded implant is variable and highly dependent on antibiotic dosing and technique. As a consequence of the higher integrity and stability of prefabricated cement implants, obese or poorly compliant patients are less likely to experience a catastrophic mechanical failure of such implant, as they are designed with enhanced articular surface congruency which confers improved anteroposterior stability of the joint, minimizing the risk of implant subluxation or dislocation (39). Surgical molds increase intraoperative time (20). Fewer fractures have been observed with prefabricated

spacers as compared to intraoperative fabricated mold spacers. However, there could be a lower concentration of antibiotics in prefabricated spacers. Prostalac is an articulating spacer which seems to induce less bone loss between stages (18). Patients are encouraged to actively mobilize the knee immediately after surgery. The rate of complications in the use of Prostalac is 17%, but it requires longer intraoperative time, and it increases the risk of cement fracture and migration of the component (18, 40). In the Hoffman technique an articulating spacer is made by cleaning and autoclaving the removed femoral component. This procedure has a good cost-effectiveness ratio. A spacer made by autoclaving the infected components has a direct cost of $932, whereas the costs of spacers made by new femoral component and molded cement spacers may reach up to $3,589 and $3,945, respectively (41). The temporary re-use of the femoral component can reduce the cost of the articulating spacer by approximately $1,900/patient, *versus* a new femoral component, and by approximately $1,000/patient, *versus* a molded cement spacer (24). Spinarelli *et al*. reported a re-infection rate ranging from 2.27 to 37%, and a cumulative re-infection rate of 13.7% (23). A recent meta-analysis reported no significant difference in reinfection compared to patients treated with other articulating spacer, but a better functional outcome (25). A systematic review of 30 retrospective studies comparing the two types of articulating spacers (all-cemented or made of bio-inert materials such as plastic or metal) reported a similar control rate of infections between the two groups. However, the articulating spacer made of bio-inert materials had a higher postoperative risk of reinfection and poorer clinical outcome (42). A meta-analysis of 34 articles compared four types of articulating spacers: 3 were all-cement (cement-on-cement handmade, cement-on cement prefabricated, cement-on-cement molded), one was metal-on polyethylene (MOP). There were no significant differences in the rate of reinfection and in the difficulty of reimplantation (43). The major complications in the use of cement-on-cement articulating spacer are extensor lag, spacer subluxation, spacer fracture, extensor mechanism rupture, nerve palsy, periprosthetic fracture, dislocation, instability, arthrofibrosis, hematoma, delayed wound healing (43). The rate of complications associated with the use of cement-on-cement handmade articulating spacers is 8.52%, against 7.69 % and 5.87% respectively of the pre-fabricated and molded ones (43). Metal-on-polyethylene articulating spacers are associated with a lower rate of complications and the absence of spacer fractures (43, 44). It is not always possible to have a second stage because of economic and health reasons, and some patients may refuse reimplantation (45). Cai *et al*. suggest using the spacer as a definitive treatment for PJI. In fact, although the infection relief rate of destination spacers was similar to that of two-stage revision, the complications were higher than those of two-stage revision (45). The use of intramedullary antibiotic dowels for the femoral and the tibial medullary canal in both static and dynamic spacers is expand-

Table III. Complications articulating and static spacers (28, 50).

Articulating Spacer	Static Spacer
Instability	Extension lag
Flexion contracture	Flexion contracture
Aseptic loosening	Aseptic loosening
Delayed wound healing	Delayed wound healing
Knee dislocation	Knee dislocation
Hematoma	Hematoma
Patella tendon rupture	Patella tendon rupture
Patella fracture	Patella fracture
Patella dislocation	Patella dislocation
Deep venous thrombosis	Deep venous thrombosis
Pulmonary embolism	Pulmonary embolism
Nerve palsy	Nerve palsy
Periprosthetic fracture	Periprosthetic fracture
Severe chronic post-operative pain	Migration of the Spacer
subluxation	subluxation
Amputation	Amputation
Fractured Spacer	Fractured Spacer

ing, given the report of frequent positive cultures in the medullary canal at the time of removal of non-stemmed infected total knee components, and the frequent finding of positive intra articular cultures in patients with a variety of knee spacers (46, 47). However, there is no significant difference in the eradication of the infection with IM dowels (48). In addition, many complications have been reported with the use of dowels including migration of a smooth pin out of a cement spacer into the calf (21). Cementless stems are associated with a lower rate of radiographic failure than cemented spacers. However, they have a similar rate of reinfection (49). The complications of static and dynamic spacers are summarized in **table III** (28, 50). Four systematic reviews have analyzed several studies comparing static and dynamic spacers. A review of 48 articles reported no significant difference between static and dynamic spacers in terms of complication, reinfection, reoperation, or knee society score. However, the mean range of motion (100° in articulating spacer *vs* 92° in the static spacer) was statistically significant (28). A systematic review of 47 studies reported a better eradication using articulating spacers, greater ROM, and easier re-implantation (50). A systematic review of 34 articles confirmed the absence of differences with reinfection or difficulty of reimplantation (43). A systematic review of 87 articles reported no differences in peri-operative local complications, rate of non-infection-related complications and rate of reinfection (13). Moreover, no correlations between the mean time to second stage after spacer placement and the mean time to PJI recurrence were found. However, articulating spacer mean active knee flexion was significantly higher using articulated spacers, but this has no clinical relevance (13).

CONCLUSIONS

Periprosthetic join infection is a common cause of failure of TKA. Two-stage revision knee arthroplasty is the gold standard for PIJ. Static spacers are used in case of joint instability, insufficiency of the extensor mechanism, massive bone loss and wound healing with skin loss. There is no evidence of superiority between the different types of articulating spacers, but patient specific characteristics such as bone stock, soft-tissue envelope, and ligamentous stability should be assessed during preoperative planning. For these reasons, the use of given spacer depends on the patient characteristics and the surgical ability of the surgeon.

FUNDINGS

None.

DATA AVAILABILITY

N/A.

CONTRIBUTIONS

FO: conceptualization, writing, revision, final approval. SZ: writing, revision, final approval. NM: supervision, revision, final approval. All authors have read and agreed to the published version of the manuscript.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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