Arthroplasty

REVIEW

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Articulating spacers: what are available and how to utilize them?

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Abstract

Periprosthetic joint infection (PJI) is the most devastating complication following total joint arthroplasty (TJA) and is posing a global healthcare challenge as the demand for TJA mounts. Two-stage exchange arthroplasty with the placement of antibiotic-loaded spacers has been shown to be efficacious against chronic PJI. This study aimed to review the key concepts, types, and outcome evaluations of articulating spacers in the two-stage exchange for PJI. Previous studies indicated that articulating spacers have been widely used due to better functional improvement and a comparable infection control rate relative to static spacers. Several types of articulating spacers are reportedly available, including hand-made spacers, spacers fashioned from molds, commercially preformed spacers, spacers with additional metal or polyethylene elements, new or autoclaved prosthesis, custom-made articulating spacers, and 3D printing-assisted spacers. However, limited evidence suggested no significant difference in clinical outcomes among the different subtypes of articulating spacers. Surgeons should be familiar with different treatment strategies when using various spacers to know which is the most appropriate.

Keywords Periprosthetic joint infection, Arthroplasty, Articulating spacer, Outcomes

Introduction

The incidence of periprosthetic infection (PJI) following total knee arthroplasty (TKA) stands somewhere between 0.5% to 2%, and the incidence after total hip arthroplasty (THA) is relatively low, being about 1% [1, 2]. Some studies reported a decreasing trend with the use of modern aseptic techniques [3, 4]. However, with the rapid growth in the number of TKA and THA, the challenge presented by PJI is becoming increasingly severe [5]. Several treatment strategies are currently available for PJI, including one-stage exchange arthroplasty, two-stage exchange arthroplasty, irrigation and debridement, and, in extreme cases, salvage surgery, all of which are associated with a high healthcare cost [6]. Given the high infection control rate, a two-stage revision with the placement of an antibiotic-loaded spacer remains the gold standard for managing chronic PJI [7, 8].

The study of antibiotic-impregnated bone cement began in the early 1970s, reporting that it could reduce the risk of PJI in primary arthroplasty [9]. In 1979, Hovelius *et al.* [10], for the first time, described using gentamicin-loaded cement spheres for infection control in the first-stage hip revision. In 1988, Cohen *et al.* [11] employed an antibiotic-polymethyl methacrylate (PMMA) spacer block to fill the joint cavity after debridement. The initial spacer was static and did not allow for joint movement. Prolonged immobilization and lack of activity can cause bone loss, joint stiffness, and soft tissue contracture, leading to severe complications at reimplantation [12]. The aforementioned issues can be solved by an articulating spacer, which allows for functional movement of the residual joint and provides better conditions for reimplantation [12]. It remains to be noted that

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articulating spacers should be avoided in cases of severe bone loss or soft tissue defect since they may not offer sufficient stability [13]. Recently, a number of studies have assessed the performance of various types of spacers in the two-stage revision, but high-quality guidelines remain scarce.

This study aimed to provide an instructional review of the key concepts, types, and outcome evaluations of articulating spacers in the two-stage exchange of PJI.

Antibiotic-loaded cement spacers

A typical knee or hip antibiotic-loaded spacer is shown in Fig. 1. Antibiotic-loaded spacers have two primary roles in two-stage exchange arthroplasty: filling the joint cavity, which tensions the soft tissues while restoring limb length, and antibiotic elution. The spacer could fill the dead space inside the joint after the removal of the prosthesis and debridement, which contributes to the maintenance of soft tissue tone and bone quality [14]. Additionally, high intra-articular antibiotic concentrations have been proven available for topical administration via spacers, enabling control of bacterial burden [15]. To effectively eliminate pathogens in biofilms, the antibiotic-loaded spacer is almost the only way to go, as it does not simultaneously increase the concentration of antibiotics in the blood or urine [14, 16]. Historically, the safety of cement spacers has been widely reported, with only a few cases reports describing toxic complications regarding spacers [17, 18].

The antibiotics loaded in the spacers should be water-soluble and resistant to high temperatures to maintain their chemical stability [15]. Aminoglycoside and glycopeptide antibiotics are the most commonly recommended [19]. Spacers can contain multiple antibiotics to broaden their antimicrobial spectrum. At the same time, single antibiotic impregnation is also optional when it is identified as a pathogen-sensitive antibiotic [20]. Another common issue is the dosage of antibiotics, which is related to several factors, including the drug-eluting properties and the bone cement's mechanical strength [20, 21]. In general, antibiotics impregnated in spacers for two-stage revision should be of high dose (>3.6 g/40 g PMMA), but excessively high dosage (>8 g/40 g PMMA, or more than 10–15 % of total cement mass) should be avoided [14, 21, 22]. Some studies recommended 3 g vancomycin and 3.6 g tobramycin per bag of cement [22].

The mixing procedures exert an impact on the elution of antibiotics. Compared to mixing in the air, vacuum mixing increases the mechanical strength and decreases the porosity of the cement. Alternatively, if the spacers are hand-made, uneven mixing of the ingredients may affect the elution of the antibiotics [20]. The bone cement and the antibiotic powder should be mixed thoroughly and evenly before mixing into the liquid. The spacer should be placed under pressure-free conditions to avoid a strong adhesion between the spacer and the bone. A standardized procedure facilitates spacer removal at reimplantation [16, 20].

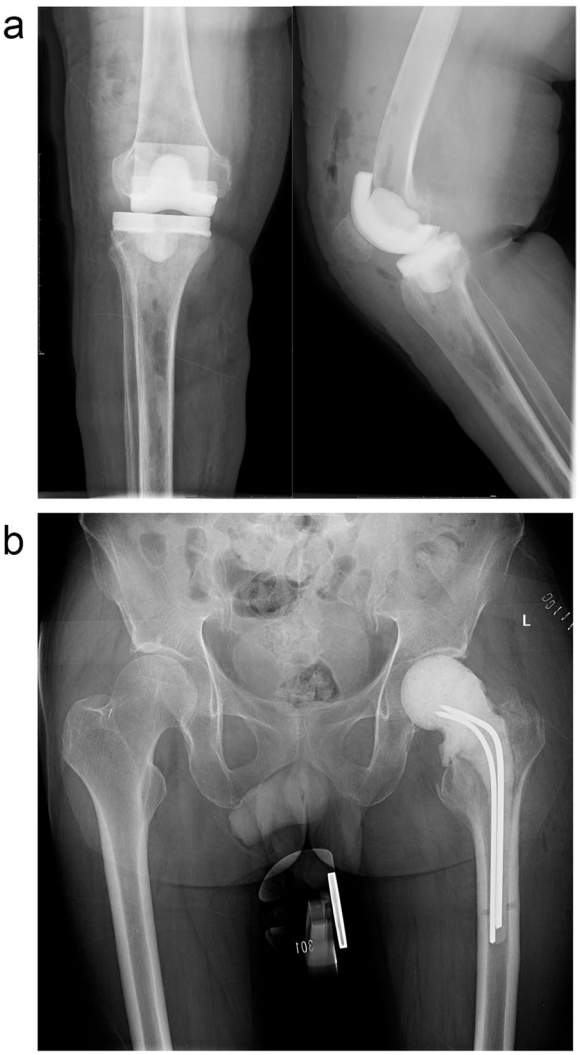

Fig. 1 An example of a typical knee (**a**) or hip (**b**) spacer

Types of articulating spacers

Hand-made spacers

Experienced surgeons can hand-make spacers intraoperatively by using antibiotic-impregnated PMMA. These spacers mimic joint anatomy or kinematics (typical ball and socket joint) [23, 24]. The apparent advantages of this spacer are the lower cost and the ability to be individually constructed to fit specific anatomical configurations. However, it can be time-consuming and carries a high risk of fracture. To address this issue and to facilitate

re-removal, "endoskeletons", such as Steinman pins, Kirschner wire, or other similar implants are often placed inside the spacer [25, 26]. Another shortcoming of hand-made spacers is the mismatch with the articulating surfaces, which may lead to instability and dislocation [27]. A spacer 2–3 mm smaller than the acetabulum in the hip PJI is recommended to help keep the spacer in place [28]. In addition, hand-made spacers can be loaded with more pathogen-sensitive antibiotics, which facilitates the eradication of infection in case of positive preoperative cultures, but this requires a balance with the mechanical properties of the spacer [29, 30]. Overall, this technique needs to be honed to make the technique clinically applicable to patients.

Spacers fashioned from molds

Spacers can also be made from homemade or commercially available molds. These spacers have a more consistent geometry and are not dependent on the surgeon for their construction. The molds are often made of silicone or stainless steel [21, 31, 32]. They are available in different sizes and can be selected intraoperatively based on a comparison against the removed prosthesis and bone anatomy. However, there is no uniformity in the size of the molds, either based on fixed increments [31] or standard prosthetic components [21, 33]. Ha *et al.* [34] described the intraoperative sterilization of the removed femoral components and polyethylene inserts, followed by the construction of a mold from the removed components using lubricant and cement. Like hand-made spacers, spacers fashioned from molds can be personalized with sensitive antibiotics, and there exists a metal endoskeleton to enhance mechanical strength in many cases [21, 35]. In clinical practice, molded spacers can also be used in some specific cases, as appropriate, such as combined acetabular cement screws, to manage bone defects (Fig. 2). Nevertheless, it is noteworthy that molded spacers reportedly increase the cost of the procedure, and their incidence of mechanical complications [13, 35].

Commercial preformed spacers

So far, a couple of preformed spacers are commercially available, such as the Tecres Spacer-G/K temporary hip/knee spacer (Tecres Spa, Sommacampagna, Verona, Italy). The most significant advantage of preformed spacers is their easy intraoperative use, which saves operative time. Preformed spacers possess more stable mechanical properties and may reduce fracture risk compared to their hand-made counterparts. The antibiotics appear to be released more evenly in the joint as the antibiotics and cement have been uniformly pre-mixed [36]. However, their relatively low antibiotic doses and restrictions on the type of antibiotic may affect their anti-infection efficacy [27, 28, 37, 38]. For instance, Spacer-K pre-mixed with gentamicin has three different sizes with antibiotic doses of 0.8–1.7 g, which are not up to the recommended dose (>3.6 g per 40 g cement) [39]. Minelli *et al.* [40] proposed a strategy to increase the dose of antibiotics in the spacer by drilling holes in the pre-fabricated spacer and filling them with vancomycin-impregnated cement. They concluded that this technique does not adversely affect the release kinetics of antibiotics.

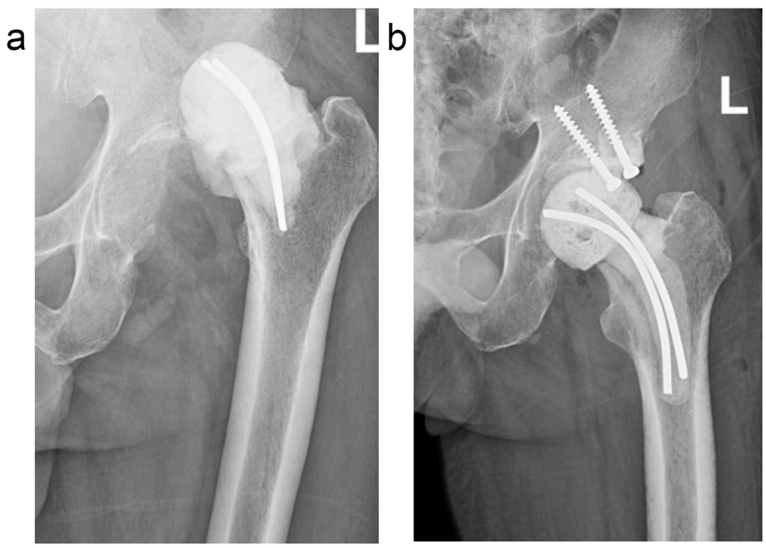

Fig. 2 Postoperative dislocation of a hand-made spacer (**a**); another molded spacer was used for spacer exchange and cemented screws were placed to manage the acetabular bone defect and increase hip stability (**b**)

Spacers with additional metal or polyethylene articulating elements

Implants designed for short-term use and with increased PMMA volume are developed for septic revision, the best known of which is PROSTALAC (prosthesis of antibiotic-loaded acrylic cement, DePuy Synthes, Warsaw, IN, USA). PROSTALAC was initially developed for septic hip revisions and has since been applied to knee [41, 42]. Typically, the system consists of a metal femoral component, a post-stabilized polyethylene tibial component, or a polyethylene acetabular liner [43]. A significant advantage is that it is designed to be semi-constrained to lower the risk of dislocation. Structurally and functionally comparable to the traditional prosthesis, it may be a cost-effective temporary spacer that can reduce the complexity of the procedure [43, 44]. In a 10- to 15-year follow-up study, 99 PJI patients using the PROSTALAC hip spacer attained an 89% long-term treatment success rate, demonstrating that it is a reliable and durable solution [45]. PROSTALAC is also promoted for complicated cases such as total femoral replacement with severe bone loss [46] or reconstruction of infected interprosthetic femoral stem fracture [47]. However, the availability of PROSTALAC is limited, and it is currently not approved for use in many countries.

New or autoclaved prosthesis

An articulating spacer with a metal-on-polyethylene interface was proposed by Hoffman *et al.* in 1995 [48]. It allows the infected femoral component to be cleaned, autoclaved, and then reimplanted with a new polyethylene liner to treat the infected TKA. After the fixation of these components with antibiotic-impregnated cement, none of the 26 patients developed reinfection. Although this technique substantially reduces the direct cost of constructing a spacer [49], it goes against recommendations of the Food and Drug Administration (USA) and the Medicines and Healthcare Products Regulatory Agency (UK) [13]. To date, several studies have further confirmed the effectiveness of similar techniques [50–54]. *In vitro* and *in vivo* studies have demonstrated the sterility of autoclaved prostheses [55, 56]. It is imperative that the surgeon should remove all periprosthetic tissues and cement before autoclaving [55, 56]. Rigid reusable sterilization containers are preferable and should be close to the operating room for easy delivery [55]. If spore testing is impossible, the prosthesis should receive full-cycle steam sterilization [55]. Similar technique was also employed in septic hip revisions. Hoffman *et al.* [57] autoclaved and reimplanted the infected femoral stem, while Evans *et al.* [58] used a new femoral prosthesis. However, caution should be exercised in interpreting these results, as autoclaving old prostheses is not allowed in many, if not most, hospitals. In this context, the use of a new prosthesis is a more normative and ethical option.

This technology offers great flexibility in two-stage exchange. It allows for partial removal of the prosthesis (Fig. 3) or use in combination with other tools to manage complications (Fig. 4). In addition, it gives the opportunity to perform a 1.5-stage exchange arthroplasty as a substitute for traditional two-stage exchange to manage PJI (Fig. 5). In a 1.5-stage exchange, the infected knee is resected, and an articulating spacer is placed with the intent to stay *in situ* as long as the patient can tolerate it [59]. Theoretically, it is advantageous in that it potentially avoids a second operation. Hernandez *et al.* evaluated 27 patients who underwent 1.5-stage exchange, and only three developed recurrent infections during a 2.7-year follow-up [59]. Nabet *et*

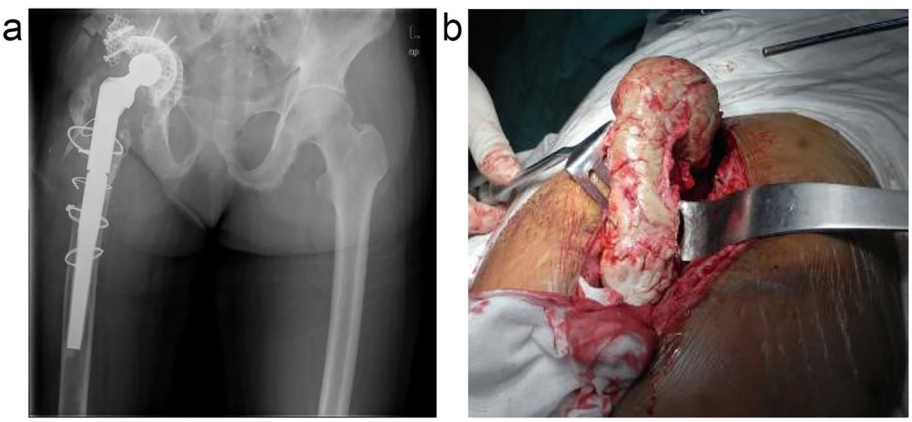

Fig. 3 A PJI case with a modular femoral stem. The femoral stem was firmly fixed and difficult to remove. After the removal of the proximal component, a spacer was placed. Pre- (**a**) and intraoperative (**b**) images are presented

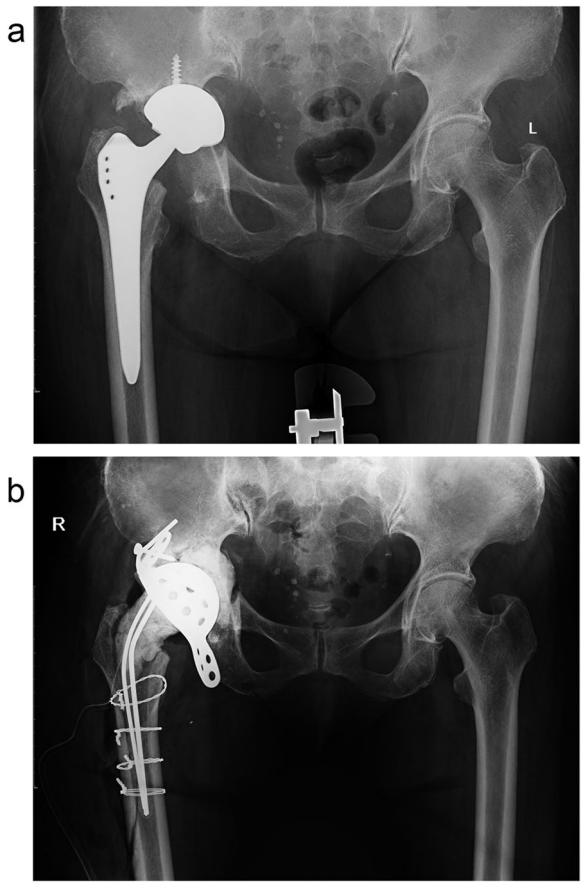

Fig. 4 A case of PJI with acetabular protrusion (**a**). Combination of a spacer and a cage to prevent central dislocation of the hip (**b**)

al. [60] further found that postoperative complications were lower among 1.5-stage exchanges compared to two-stage exchanges.

Custom-made articulating spacers (CUMARS)

CUMARS was developed in 2001, and this spacer system includes the Exeter Universal Femoral stem (Stryker, Mahwah, NJ, USA) and a polyethylene acetabular liner [61]. It is comparable, in treatment principles, to PROSTALAC, but its components are more common and readily available [61]. They provide better joint function during the pre-reimplantation period, allowing for full weight-bearing of the lower extremity. More recently, CUMARS was extensively reported to be associated with better inter-stage functionality, easier removal, and excellent infection control [62–65]. Moreover, for low-demand patients with severe comorbidities, a large volume of antibiotic-impregnated cement can be used to hold the spacer in place as firmly as possible [61]. These so-called "long-term spacers" may obviate the need for reimplantation, a potential approach to 1.5-stage exchange arthroplasty [61, 63]. Besides, Quayle *et al.* [62] described use of a modified CUMARS with a long femoral stem to treat PJI with severe bone loss. However, due to the high cost, further evaluation of the cost-benefit of CUMARS is needed. Recently, Craig *et al.* [13] recommended using CUMARS as an articulated spacer whenever possible: a knee cemented femoral component and a polyethylene tibial component, or a cemented, polished, tapered femoral stem with cemented socket (kiwi procedure).

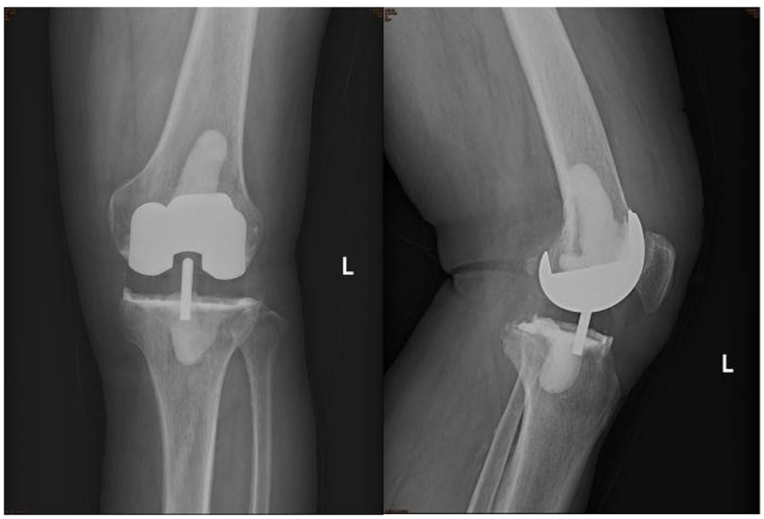

Fig. 5 The new prosthesis was combined with high-concentration bone cement for a 1.5-stage exchange, using a Press Fit Condylar femoral component (PFC, DePuy Synthes, Warsaw, IN, USA) and a constrained polyethylene insert

3D printing-assisted articulating spacers

3D printing technology allows for rapid prototyping based on each individual's unique anatomical configuration, thereby improving the match between components and joints. Previous evaluation of 3D models of spacers by using an "*ad hoc*" virtual planning simulator revealed a strong correlation between the geometric characteristics of the spacer and clinical improvement [66]. In recent years, 3D printing-based spacers have been proposed to enhance joint function and stability [67]. Tsai *et al.* [68] suggested that 3D models with high geometric consistency could be obtained by analyzing the removed femoral and tibial prostheses through reverse engineering techniques. The original models were then scaled up while maintaining the geometry to yield femoral and tibial models of different sizes. The infection eradication rate in their study was 87.5 % (28/32) and mechanical complications occurred in two cases, demonstrating a good prospect of computer-aided design and manufacturing of spacers. Kong *et al.* [67] analyzed CT images of the patient's contralateral knee to determine the spacer's size and design the mold. They also modified the structure of the anterior condyle, diseased carriage, tibial column, and tibial platform sliding interface. This technique improved the quality and function of the spacer, increased stability, and reduced dead space inside the joint. What is more, Kim *et al.* [69] explored the use of 3D-printed polylactic acid (PLA) to construct spacers. PLA spacers have superior mechanical properties to PMMA and can elute antibiotics in a controlled manner. Despite the unlimited potential, we must be aware that the above-mentioned studies are either small-scale or still confined to *in vitro* experimentation. The lack of relevant medical regulations and consensus is another limitation.

Modification of spacers

The femoral component for hip spacers should utilize a metal scaffold to reduce the risk of spacer fracture. For example, when an extended trochanteric osteotomy (ETO) is performed, a Steinmann Pin fixed to the bottom of a cemented femoral stem coated with cement creates a construct that bypasses the distal-most extent of the osteotomy. Bone loss in infected revisions is challenging, and small-to-medium-size defects can be managed with a variety of techniques. The application of screws and cement acetabular augmentation can improve acetabular coverage and mitigate the risk of mechanical failure [70]. Additionally, a large-diameter highly cross-linked polyethylene liner with a backside roughened with a burr may be cemented into place. This technique is useful in lowering the postoperative dislocation rate [71]. As for severe bone loss in an infected knee, a static spacer is preferred. Components with augments or stems are available for reimplantation to further enhance joint stability [72]. No consensus has been reached on the optimal design of the spacer, and more investigations are warranted to meet the needs in varying clinical scenarios.

Comparison of clinical outcomes

Practically all studies investigating antibiotic-loaded spacers in two-stage exchange revisions have shown similar infection eradication rates using static and articulating spacers, in both the hip and knee [21, 73–76]. Studies on different types of hip spacers have indicated that articulating spacers improved joint function more significantly; nevertheless, some failed to show differences in functional scores [13, 28]. A recent multicenter randomized trial exhibited similar results for static and articulating spacers in the treatment of THA PJI. Still, static spacers were significantly associated with extended length of hospital stay, which may place a substantial financial burden [77]. As for the TKA PJI, several systematic reviews noted that functional scores after reimplantation were similar in both groups but that using an articulating spacer resulted in a better range of motion (ROM) [78–80]. Another recent randomized controlled trial demonstrated that articulating spacers provided higher knee association scores, greater ROM, and shorter hospital stay [12]. Besides, comparative studies have shown that articulating spacers facilitated the preservation of the remaining bone mass, but spacer-related mechanical complications are more common [80, 81]. However, we should be aware of the selection bias between static and articulating spacers in the interpretation of these results: The former can be used in more complicated clinical situations, especially when there exist accompanying severe soft tissue defects. We should concede that static spacers may be favoured over articulating spacers in the cases with poor soft tissue envelope, bone loss, or abductor deficiency [82].

Studies comparing the clinical outcomes using specific subtypes of articulating spacers are scanty. DeBoer *et al.* [83] found comparable efficacy between injection molded and prefabricated articulating spacers. In a systematic review [84] comparing 394 patients receiving autoclaved components and 173 patients with spacers made from new components, Spinarelli *et al.* showed that reinfection rates were similar in both groups, and postoperative ROM was greater in patients with autoclaved components. Another recent study revealed that real-component spacers significantly improved patient comfort compared to all-cement articulating ones [85]. Citak *et al.* [37] analyzed 1631 infected THAs and revealed that preformed articulating spacers were not superior to hand-made spacers in terms of functional outcomes and infection eradication. However, preformed articulated

spacers reduced the risk of spacer fracture. Veltman *et al.* [73] reviewed 25 hip studies and found similar infection eradication rates among custom spacers (95 %), prefabricated spacers (96 %), and functional articulating spacers (93 %). In another study concerning TKA PJI, Nodzo *et al.* [6] found no difference in surgical success among homemade molds, autoclaved femoral components, or prefabricated spacers, with the cost being the lowest when molds were used. On the basis of different classification methods, a systematic review indicated that spacers containing bio-inert materials and all-cement spacers had similar infection control rates [86]. Another study by Spivey *et al.* [87] demonstrated increased temporary ROM of metal-on-polyethylene spacers and fewer spacer-related complications. However, we must be aware that multiple factors might confound these results, including surgical technique, case complexity, antibiotic administration, *etc*. Besides, it should be noted that with all articulating spacers in which cement articulates with bone, there is a risk of acetabular bone loss. A retrospective study found progressive acetabular bone loss in 43% of patients following explant and spacer placement [88].

Conclusions

Two-stage exchange arthroplasty with the placement of antibiotic-loaded spacers has been performed successfully in chronic PJI. Many types of spacers are available for clinical selection, but there is still no definitive evidence of the optimal approach. Articulating spacers appear to provide better functional improvement compared to their static counterparts with a similar rate of infection eradication. Limited evidence suggested no significant difference in clinical outcomes among the different subtypes of articulating spacers. Surgeons should be familiar with the treatment strategies using various spacers to decide which is the most appropriate.

On the basis of our practice, we are inclined to advocate dynamic spacers. We only choose static spacers when knee stabilization is difficult to achieve, for instance, when there are severe soft tissue deficiencies or substantial bone loss. Dynamic spacers are generally used in the hip joint unless multiple spacers have been placed and failed to eradicate the infection. Spacers fashioned from molds are more frequently employed due to their reliable function and cost-effectiveness. In complicated cases, 3D-assisted printed spacers and new prostheses in the 1.5-stage exchange can provide more individualized and flexible treatment options.

Abbreviations

PJI	Periprosthetic joint infection
TJA	Total joint arthroplasty
TKA	Total knee arthroplasty
THA	Total hip arthroplasty
PMMA	Antibiotic-polymethyl methacrylate
CUMARS	Custom-made articulating spacers
PLA	Polylactic acid
ROM	Range of motion

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Authors' contributions

Z.L.: Study design, literature review and manuscript writing. C.X.: Literature review and manuscript editing. J.C.: Study design, manuscript editing, and supervisor. All authors read and approved the final manuscript.

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Availability of data and materials

Not applicable.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

Jiying Chen is a member of the Editorial Board of ***Arthroplasty*** and other authors declare that they have no competing interests. All authors were not involved in the journal's review of or decisions related to this manuscript.

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