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Fixed- versus mobile-bearing unicondylar knee arthroplasty: are failure modes different?

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Abstract
Purpose An ongoing controversy exists on whether mobile-bearing design is superior over fixed-bearing design in unicondylar knee arthroplasties (UKAs). The present study conducted a systematic review to ascertain differences in performance between fixed- and mobile-bearing designs in UKAs.
Methods A literature search was performed in PubMed, Embase, Scopus and the Cochrane Library. A total of 9 comparative studies involving 915 knees comparing outcomes of mobile-bearing UKAs with fixed-bearing UKAs were included in the current analysis. Outcomes of interest included knee function, quality of life, radiographic outcomes, reasons and incidence of reoperation, timing of failures, and survivorship.
Results The results presented no significant differences between the two designs in terms of knee scores, range of motion, limb alignment, implant positioning, incidence of radiolucent lines and overall reoperation rates. However, their differences have been noted in their modes and timing of failures. Early failures are related to the risk of bearing dislocation in the mobile-bearing design. In contrast, later failures are related to the risk of polyethylene wear in the fixed-bearing design.
Conclusions The available evidence has not confirmed the advantage of mobile-bearing UKAs over fixed-bearing UKAs but pointed out specific modes of failure.
Level of evidence Therapeutic study (systematic review and meta-analysis), Level III.

Keywords Fixed-bearing · Mobile-bearing · Meniscal-bearing · Unicondylar knee arthroplasty · UKA

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Introduction

A variety of surgical options are available in the treatment of isolated compartment arthritis of the knee [8, 24, 62]. These options include unicondylar knee arthroplasty (UKA) and total knee arthroplasty (TKA). Early published outcomes of the UKA have shown unfavourable performance with subsidence, loosening, high wear and progression of arthritis to the remaining compartments [40, 48]. Recently, performing UKA has been a resurgence of interest, considering the advances in surgical technique, instrumentation, material and implant design [11, 12, 35, 59]. Numerous studies have suggested good survivorship and excellent function for selected patients with intact anterior cruciate ligaments and unicompartmental osteoarthritis following UKAs, even among the active and obese population [17, 41, 66]. The proposed advantages of the UKA include smaller incision, less blood loss [26, 65], greater range of motion (ROM) [36, 46], faster recovery [18, 47, 50], lower perioperative morbidity [19, 46], preservation of normal kinematics [36, 52] and less overall costs [56, 64]. Furthermore, conversion of a failed UKA to TKA is not as complicated as a revision TKA due to the preservation of bone stock and sparing of ligaments [27, 37, 60].

Currently, two different fundamental design concepts are available on UKAs: fixed-bearing (FB) and mobile-bearing (MB) knee prostheses [4, 16, 63]. MB design proponents cite the potential advantages of a congruent bearing with lower contact stresses and polyethylene wear rates [44, 45, 61]. In addition, the mobile design is considered to recreate native knee kinematics more closely [1]. MB design has been experiencing an increase in popularity due to its theoretical advantages over the FB design. However, several clinical studies have not been consistent in demonstrating the advantages of one bearing design over the other [3, 7, 9, 15, 16, 21, 39, 51, 67]. In three cohort studies [16, 51, 67], no mid-term differences and long-term differences in survivorship were found between these two designs in UKAs.

The debate of whether MB UKA offers clinical and radiographic advantages over FB UKA for isolated end-stage symptomatic osteoarthritis of the knee has continued to generate substantial controversy in the orthopedic community [5, 42, 63]. Although there is already a meta-analysis on clinical differences between fixed- and mobile-bearing UKAs [63], more RCTs have been coming out with different outcomes in the past few years [3, 7, 51, 67]. The present study has presented an evidence-based review to determine whether the MB and FB designs of medial UKAs differ in knee score, ROM, quality of life, radiographic outcomes, reasons and incidence of reoperation, timing of failures, and survivorship.

Materials and methods

Only studies meeting the following criteria were included in this systematic review: (1) prospective and retrospective studies directly comparing MB with FB knee prostheses; (2) patients with isolated medial compartment arthrosis of the knee; and (3) reported clinical and radiographic outcomes of UKAs. All patients in these studies were scheduled to undergo their primary UKA surgery. Studies with the following conditions were excluded from the present study: (1) all case reports, case series, comments, letters, editorials, expert opinions, review and other non-comparative studies; (2) publications presenting data from national registries; and (3) in vitro/vivo wear testing, cadaver study and retrieval specimen study.

Two reviewers performed a systematic search of the medical literature published between January 1990 and December 2011 independently. The searched sources included PubMed, EMBASE, Scopus and the Cochrane Central Register of Controlled Trials. The search strategy was based on combinations of “fixed-bearing”, “mobile-bearing”, “meniscal-bearing”, “unicondylar”, “unicompartmental”, “replacement” and “arthroplasty”. In addition, these electronic searches were supplemented with manual searches in published articles, major orthopedic textbooks and table of contents from six major orthopedic journals, namely *The Journal of Bone and Joint Surgery* (American and British volumes), *Clinical Orthopedic and Related Research*, *The Journal of Arthroplasty, The Knee*, and *Knee Surgery Sports Traumatology Arthroscopy*. No restrictions regarding the language of publication were imposed.

The two independent reviewers extracted the relevant data in duplicate, including number of patients/knees, preoperative diagnosis, demographic data (age, sex, weight, height, etc.), duration of the follow-up, type of prosthesis, surgical approach, and clinical and radiographic outcome measures. They assessed the levels of evidence from the included articles according to the rating measure published in *The Journal of Bone and Joint Surgery* (American Volume) [68]. The outcome measures of the current study included knee scores, ROM, quality of life, limb alignment, implant positioning, radiolucent lines (RLLs), reason and incidence of reoperation, timing of failure, and survivorship.

Statistical analysis

Statistical analysis for categorical variables was carried out using risk ratio (RR) as the summary statistic. For continuous variables, statistical analysis was carried out using the weighted mean difference (WMD) as the summary statistic. The outcome measure tested was assessed for heterogeneity by measuring the chi-square statistic and calculated I^2. A value of less than 25 % was considered low heterogeneity, 50 % moderate heterogeneity and 75 % high heterogeneity [25]. In any case, a random effects model (DerSimonian-Laird method) was used to calculate the summary WMD/RR and 95 % CI. The random effect model assumes variation among studies, and therefore, the calculated ratio has a more conservative value [10]. The present work estimated publication bias using a graphical method (funnel plot). Statistical analyses were performed with the Review Manager version 5.0 for Windows XP (Copenhagen: the Nordic Cochrane Centre, Cochrane Collaboration) and SPSS version 13.0 for Windows (SPSS Inc., Chicago, Illinois).

Results

Initial electronic and manual search identified 303 studies. A total of 160 were excluded for the following reasons: (1) UKA revision; (2) lateral UKA; (3) cadaver study; (4)

retrieval study; and (5) in vivo/vitro wear analyses. The remaining 143 studies were retrieved for more detailed evaluation. Next, 68 studies were excluded for the following reasons: they included data from national registries; they are traditional or systematic literature reviews; they did not have control group; and they did not present outcome of interest. A total of 9 studies reporting 797 participants (915 knees) met the eligibility criteria of the present work. A flow diagram is shown in Fig. 1. From the 9 studies, 3 were RCTs/qRCTs [9, 21, 39] and 6 were retrospective comparative studies [3, 7, 15, 16, 51, 67]. One study [15] omitted the patient's age and gender. The other 8 studies demonstrated that the total MB population included 160 males and 191 females with mean age ranging from 63 to 74 years. The total FB population was 202 males and 264 females with mean age ranging from 62.8 to 70.3 years. Mean weight or body mass index was reported in five studies [16, 21, 39, 51, 67]. Preoperative knee score was reported in three studies [9, 21, 51]. Preoperative limb alignment was reported in three studies [15, 16, 51]. Mean height was reported in only two studies [7, 16]. Most studies assessed whether the two treatment arms are comparable with important preintervention parameters, such as age, sex, weight and ROM, which can affect postoperative outcomes following UKAs. The mean follow-up period range was from 12.4 months to 17.2 years; the follow-up period was not stated in one study [15]. In seven studies, the follow-up period duration was beyond 4 years [3, 7, 9, 16, 21, 51, 67], whereas in one study, it was beyond 10 years [51]. Table 1 shows additional details about study characteristics and participant demographics.

The 9 eligible studies noted the use of FB knee prostheses from five manufacturers: Miller-Galante (Zimmer), Robert Brigham (Johnson & Johnson), St.Georg (LINK) and Optetrak (Exactech). The MB knee prostheses were from two manufacturers: AMC (Alphanorm) and Oxford (Biomet). Although most of the reports included conventional criteria for patient selection, the indication of the index procedure varied among these studies to a certain

Fig. 1 Flowchart for the identification of eligible studies

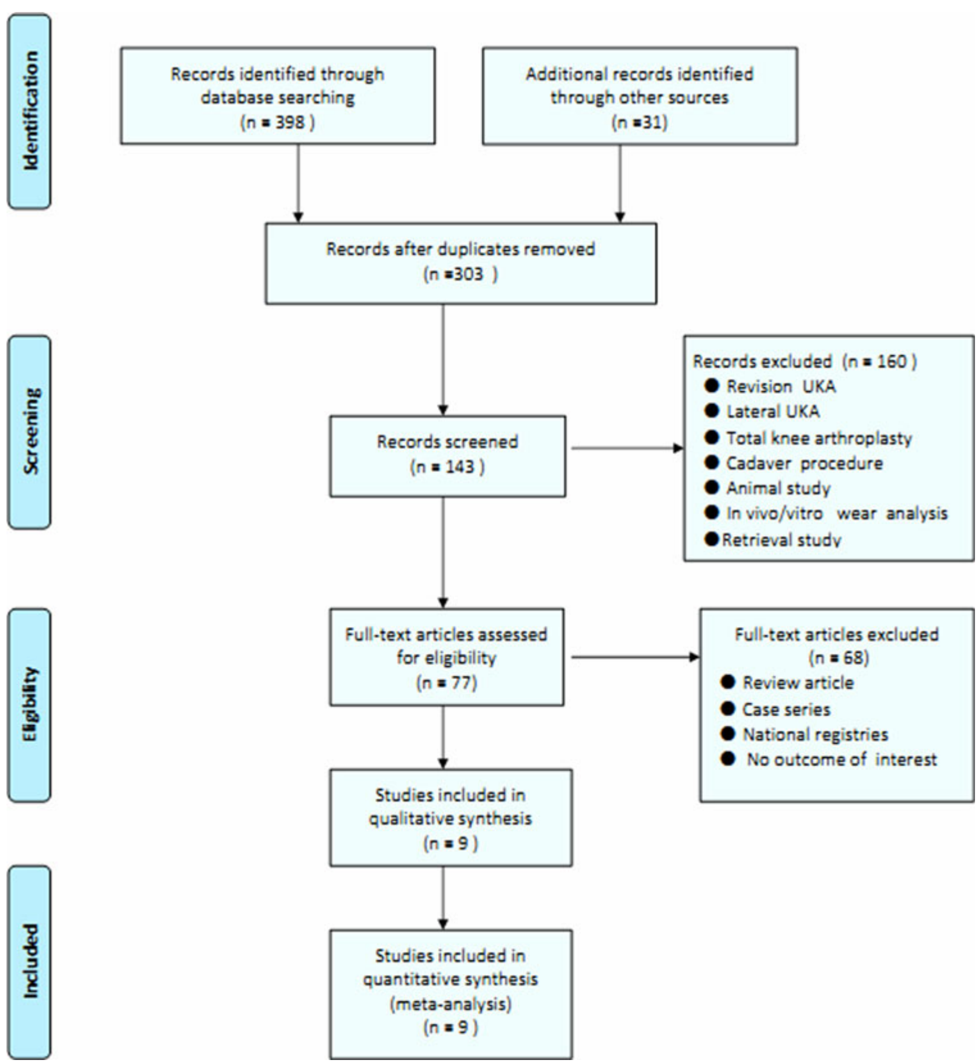

Table 1 Study characteristics and participant demographics

Author (Year of publication, country of origin)	Level of evidence	Preoperative diagnosis	Number of patient/knee	Mean/median age (years) (range)	Gender (male/female)	BMI/weight (range)	Mean length of follow-up (range)
Bhattacharya et al. [3] (2012, UK)	III	Medial OA	MB: 44/49	68.8 (50–83)	22/22	NA	67.6 months (24–119)
			FB: 79/91	67.7 (48–88)	33/46		44.7 months (24–74)
Catani et al. [7] (2011, Italy)	III	Medial OA, AVN	MB: 10/10	70.3 ± 5.8	2/8	75.4 ± 11.9 kg	46.1 ± 24.8 months
			FB: 10/10	70.3 ± 7.6	4/6	76.5 ± 14.4 kg	12.4 ± 0.7 months
Confalonieri et al. [9] (2004, Italy)	I	Medial OA	MB: 20/20	71	11/9	NA	5.7 years
			FB: 20/20	69.5	8/12		
Emerson et al. [15] (1992, USA)	III	Medial OA	MB: 21/27	NA	NA	NA	NA
			FB: 39/42				
Emerson et al. [16] (2002, USA)	III	Medial OA	MB: 43/50	63 (38–85)	22/28	175 Ib (112–240)	6.8 years (2–10.9)
			FB: 45/51	63 (33–84)	18/33	186 Ib (104–275)	7.7 years (2–10.9)
Gleeson et al. [21] (2004, UK)	I	Medial OA, AVN, RA	MB: 43/47	64.7	17/26	77.7 kg	4 years (2.7–5.3)
			FB: 49/57	66.7	20/29	83.0 kg	
Li et al. [39] (2006, Australia)	I	Medial OA	MB: 24/28	74	20/8	26.5	2 years
			FB: 24/28	70	19/9	27.6	
Parratte et al. [51] (2011, France)	III	Medial OA, AVN, PTA	MB: 72/77	63.4 ± 11	25/52	27 ± 3 kg/m^2	17.2 ± 4.8 years (15–21.2)
			FB: 75/79	62.8 ± 9.2	29/50	26 ± 4 kg/m^2	
Whittaker et al. [67] (2010, UK)	III	Medial OA, AVN	MB: 62/79	63 (49–87)	41/38	30.7 (19.3–43.1)	3.6 years (1–11.3)
			FB: 117/150	68 (45–79)	71/79	28.7 (16.8–44)	8.1 years (1–17.8)

BMI body mass index; *MB* mobile-bearing; *FB* fixed-bearing; *OA* osteoarthritis; *AVN* avascular necrosis; *RA* rheumatoid arthritis; *PTA* posttraumatic arthritis; *NA* not applicable degree. The indication/contraindication proposed by Kozinn and Scott [33] was applied to patients with UKA in four studies [7, 15, 16, 39], and three other studies [3, 21, 67] adhered to the criteria of Goodfellow et al. [22].

Knee score and ROM

Five studies assessed the Knee Society Score (KSS) [9, 16, 39, 51, 67]; two studies assessed the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score [39, 67]; one studies assessed the Oxford Knee Score (OKS) [21]; one study assessed the Italian Orthopaedic UKR's Users Group(GIUM) score [9]; one study assessed the International Knee Society score [7]; and one study assessed the Bristol knee score [21]. These studies reported no significant statistical differences between MB and FB patients on all knee scores measures. Although statistical heterogeneity was high in the assessment of KSS (knee score and function score; $I^2 = 87$ % and $I^2 = 89$ %, respectively), data from meta-analysis did not show significant statistical differences between FB and MB UKAs ($P = 0.92$ and $P = 0.16$, respectively). Postoperative ROM or flexion was assessed in four studies [8, 22, 40, 54]. On review, all studies reported similar ROM or flexion for both groups ($P = 0.4$; WMD = 3.4; 95 % CI, −4.6 to 11.2).

Quality of life

Quality of life was measured using two methods: Short Form (SF)-12 and SF-36. Li et al. [39] found that SF-36 scores improved significantly from preoperative to 2 years postoperatively in both groups without significant differences between the groups. Whittaker et al. [67] observed higher scores in the MB group in the SF-12 scores at the latest follow-up for both mental ($P = 0.04$) and physical ($P = 0.04$) components compared with the FB group.

Radiographic assessments

According to the Kennedy classification [30], malalignment of the knee is defined as a deviance from Zone 2 or C. It occurred in 11.2 % of knees in the MB group versus 12.5 % of knees in the FB group ($P = 0.7$; RR = 0.9; 95 % CI, 0.5–1.7). The MB group displayed the following postoperative results: 135 knees had correct alignment, 2 knees had alignment in varus, and 15 knees had alignment in valgus. The FB group displayed the following postoperative results: 147 knees had correct alignment, 13 knees had alignment in varus, and 8 knees had alignment in valgus.

Based on the radiographs, the frequency of RLL was higher in the MB group than in the FB group (30.8 vs. 12.5 %), but their difference was not significant ($P = 0.8$, RR = 0.8; 95 % CI, 0.1–5.7).

Reason and incidence of reoperation, timing of failures, and survivorship

In the MB group with a mean of 5.0 years (range of 0.1–17.7), 41 knees experienced failure and underwent subsequent reoperations. Reoperations were performed for aseptic loosening in 13 patients with a mean of 5.9 years (range of 1.0–17.7); progression of osteoarthritis in 12 patients with a mean of 7.4 years (range of 2.9–11.0); bearing dislocation in 7 patients with a mean of 0.4 years (range of 0.2–0.7); postoperative persistent pain in 2 patients with a mean of 3.3 year (range, 2.8–3.7); postoperative infection in 2 patients with a mean of 6.5 years (range of 0.1–12.9); detained cement in 2 patients; atraumatic medial tibial plateau fracture in 1 patients at 8 months; bearing impingement in 1 patient at 3 years; and inflammatory arthritis in 1 patient at 2 years.

A total of 52 knees from the FB group were reoperated on at a later mean of 6.3 years. The failure occurred in 15 patients for polyethylene wear at a mean of 8.3 years (range of 2.0–14.3 years); 14 patients for progression of osteoarthritis at a mean of 7.1 years (range of 2.0–15.0); 13 patients for aseptic loosening at a mean of 5.7 years (range of 2.0–14.6); and six patients for persistent pain at a mean of 3.8 years (range of 1.5–7.2). Two additional patients were reoperated for tibial fracture and instability following trauma at 31 months and 3.4 years, respectively. A single patient had a reoperation due to septic loosening at 0.3 years. One FB knee was reported as having detained bone cement that needed surgery to remove the cement segment.

Significant difference was observed in the mean time for reoperation between the two groups, the number favoured FB prosthesis ($P = 0.016$). The frequencies for aseptic loosening, persistent pain, progression of arthritis or overall reoperation between the two groups were not significantly different. However, the differences in frequency of bearing dislocation and polyethylene wear were statistically significant between the two groups (Fig. 2).

Three studies addressing MB and FB UKAs reported survival rates of 80–97 %, with a mean follow-up ranging from 3.6 to 17.2 years [16, 51, 67] (Table 2). These studies suggested that no significant difference in implant survivorship occurred between the two groups. However, Bhattacharya et al. [3] compared the survival of the two implants using the Cox regression analysis model, showing that the FB prosthesis has the worse survivorship ($P < 0.05$).

Publication bias

Publication bias was assessed with funnel plots, which demonstrate the relationship between the study sample size and the precision in estimating the treatment effect. The

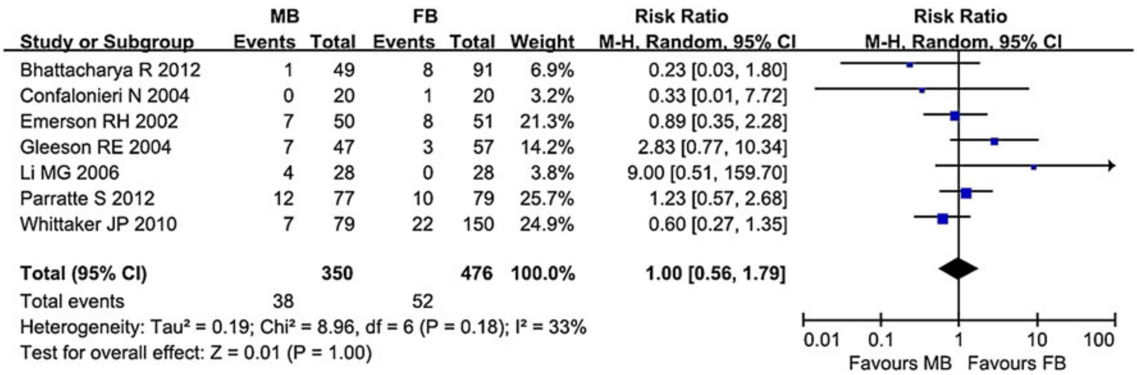

Fig. 2 Forest plot for reoperations following UKAs

Table 2 Results of survivorship in unicondylar knee arthroplasties

Study	Number of knees	Survivorship/revision rate		Mean follow-up duration		*P* value
		MB	FB	MB	FB	
Bhattacharya et al. [3]	140	2.0 %[a]	8.8 %[a]	67.6 months	44.7 months	$P < 0.05$
Emerson et al. [16]	101	97 % at 6 years	95 % at 6 years	6.8 years	7.7 years	n.s.
		92 % at 11 years	92 % at 11 years			
Parratte et al. [51]	156	80 % at 20 years	83 % (0.74–0.92) at 20 years	17.2 ± 4.8 years		n.s.
		(95 % CI, 0.81–0.95)	(95 % CI, 0.74–0.92)			
Whittaker et al. [67]	229	89 % at 5 years	96 % at 5 years	3.6 years	8.1 years	n.s.
		(SE ± 0.46)	(SE ± 0.18)			
		89.3 % at 5 years	95.6 % at 5 years			
		(SE ± 0.04)[b]	(SE ± 0.02)[b]			

CI confidence interval, *SE* standard error

[a] Revision rate

[b] Survival rate was calculated for a worst-case scenario

funnel plot visually demonstrated mild asymmetry, suggesting minimal evidence of publication bias (Fig. 3).

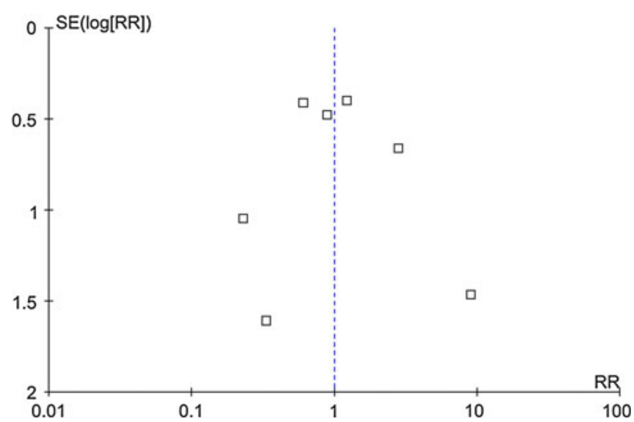

Fig. 3 Funnel plot demonstrating minimal publication bias from reoperation outcome

Discussion

The most important finding of the present study was that the two designs in UKAs did not differ in the following: (1) knee score; (2) quality of life; (3) radiographic outcomes; and (4) incidence of reoperation. However, their differences have been noted in their modes and timing of failures. Early failures are related to the risk of bearing dislocation in the mobile-bearing design. In contrast, later failures are related to the risk of polyethylene wear in the fixed-bearing design.

In the current study, the frequency of RLL was higher in the MB group than the FB group. However, the difference was not significant. Periprosthetic RLLs following UKAs have been described as inclusive of two subtypes (physiological and pathological), but their etiological significances remain unclear [28]. Many authors found that the presence of RLLs is not associated with lower knee scores or higher revision rates in mid- and long-term follow-up study [23, 51, 55, 67]. Price et al. [55] followed-up 89 patients with

114 medial Oxford UKAs. They reported a 15-year survivorship of up to 92 % with complete RLLs in 96 % of the cases around the tibial component. Whittaker et al. [67] found that patients with non-progressive RLLs continue to function well without symptoms and subsidence. Parratte et al. [51] reported a high incidence of RLLs in MB and FB prostheses (69 and 24 %, respectively) at a minimum follow-up of 15 years. Survivorship for patients with or without RLLs did not differ. Although the sensitivity and specificity of RLLs using standard radiographs appear to be acceptable, their intraobserver and interobserver reliabilities were poor [28]. If a non-parallel X-ray beam obscures their characteristic features, the RLLs will be missed unless fluoroscopic control is used in the tibial component of Oxford UKA [23]. To improve the zonal reliability of the assessment of RLLs, some authors suggested that fluoroscopically guided radiographs may be used [23, 28].

Interestingly, the current research clearly demonstrated a lower incidence with polyethylene wear in MB design. One major goal of the MB design is to reduce the overall polyethylene wear by increasing the contact area and congruency while minimizing the constraint and maintaining the normal knee motion [29]. Retrieval studies reported low wear rates (0.01–0.043 mm/year) in well-functioning MB UKA through in vivo measurement [14, 29, 53]. The maximum linear penetration reported for MB UKA was an order of magnitude lower than that reported for FB UKA (0.15 mm/year) [2, 14]. Manson et al. [43] examined wear damage of three modern UKAs, including two FB and one MB design. They found that delamination and surface deformation are more common in FB designs. It should be noted, however, that in contrast to the above-mentioned studies, in vitro wear analysis found that fixed-bearing design is superior over mobile-bearing design. Brockett et al. [6] compared the wear performance of a low-conformity FB UKA with a conforming MB UKA using a physiological knee wear simulator. Under identical kinematic conditions, the relatively low-conforming FB prosthesis showed lower wear compared with the more conforming anterior–posterior sliding MB prosthesis. Another knee simulator study, limited to level walking, found that the MB design exhibits higher wear rates than the FB design [34].

Early UKAs from mid-term follow-up had a high failure rate of 15–28 % for aseptic loosening, polyethylene wear and progression of osteoarthritis [40, 42, 44, 48–50, 63]; however, recent clinical literature showed a steady improvement, with excellent mid- and long-term survivorship for both FB and MB UKAs [13, 16, 51, 54, 67]. Earlier data from a Swedish multicenter survival study showed that the MB UKA has twice the revision rate of the FB UKA [38]. Later arthroplasty registries comparing FB and MB UKAs did not confirm the superiority of one design over the other in knee function and survivorship [31, 32, 57, 58]. Some studies by surgeons, who have designed UKAs or are from specialized centres, tended to report more favourable outcomes [35, 55]. In a report from the Swedish Arthroplasty Registry, Robertsson et al. [57] found that revision rate is related to the annual surgical volume of Oxford UKA. They suggested greater learning curve and higher technical demands for the MB design, which could partially explain the difference in the reported outcomes. Given that excellent survivorship for a UKA has been documented, high-quality RCT with longer-term follow-up is required to assess the true differences in implant longevity of UKAs performed by experienced surgeons.

The design of the current study had several limitations. More than half of the studies reviewed were retrospective cohort studies. The retrospective nature of these studies, which is more susceptible to selection bias than prospective studies, precluded the ability of the present work to control confounding factors [20]. Additionally, publication bias may have affected the results; the present review did not search unpublished studies. However, the funnel plot demonstrated minimal evidence of publication bias.

Conclusion

In conclusion, both bearing designs have provided excellent knee function and survivorship in UKAs. The available evidence has shown similar performance of MB design in comparison with FB design in UKAs, regardless of the confounding factors that have been detected in the present study. The current review has not confirmed the superiority of one design over another in knee function, implant alignment and overall reoperation rate but has pointed out specific modes of failure.

Conflict of interest No benefits or funds were received in support of the study.

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