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Original Article

The Role of Preoperative Patient Characteristics on Outcomes of Unicompartmental Knee Arthroplasty: A Meta-Analysis Critique

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A B S T R A C T

Background: In 1989, Kozinn and Scott introduced strict exclusion criteria for unicompartmental knee arthroplasty (UKA). Because outcomes have improved with modern techniques and implants, these criteria have now been challenged. Therefore, the goal was to assess the role of these criteria on (1) functional outcomes and (2) revision rates of medial UKA. The hypothesis was that, with modern surgical techniques and implants, these traditional exclusion criteria are no longer strict contraindications for UKA.
Methods: Databases of PubMed, EMBASE, and Cochrane and annual registries were searched for studies comparing UKA results in subgroups: age (young vs old), gender (male vs female), body mass index (obese vs nonobese), present vs absent patellofemoral osteoarthritis, and intact vs deficient anterior cruciate ligament.
Results: Thirty-one comparative cohort studies (7 level II and 24 level III/IV studies) and 6 registries reported outcomes in 17,147 patients and revision rates in 285,472 patients. Females had inferior functional outcomes compared to males (odds ratio [OR], 4.03; 95% CI, 1.77-6.30). Furthermore, younger patients (in studies: OR, 1.52; 95% CI, 1.06-2.19; in registries: OR, 2.09; 95% CI, 1.70-2.57) and females (OR, 1.13; 95% CI, 1.06-1.21) had increased likelihood for revision. No increased likelihood for inferior outcomes or revisions was detected in patients with obesity, preoperative patellofemoral osteoarthritis, or anterior cruciate ligament deficiency.
Conclusion: Findings of increased revision risk in younger patients and increased revision risk with inferior outcomes in females give a more nuanced perspective on historical criteria, such that surgical decision-making may be based on UKA outcome data for subgroups rather than strict exclusion criteria.

The first results of unicompartmental knee arthroplasty (UKA) for patients with isolated unicompartmental osteoarthritis (OA) were disappointing with revision rates up to 30% at 6-year follow-up [1,2]. In 1989, Kozinn and Scott [3] proposed strict patient selection criteria to optimize these results. The authors suggested restrictions for UKA including (1) age older than 60 years, (2) nonobese, (3) intact anterior cruciate ligament, and (4) no signs of patellofemoral OA (PFOA). Adherence to these guidelines, along with improved implant designs and advances in surgical technique has contributed to better outcome scores, lower revision rates, and increase in overall UKA utilization [4-10].

Currently, UKA comprises 8%-12% of all knee arthroplasties [11-13]. With the increased use of UKA, several studies have assessed the effect of the Kozinn and Scott selection criteria (ie, age, body mass index, preoperative PFOA, and anterior cruciate ligament [ACL] deficiency) on outcome scores and revision rates [14-18]; in addition, the role of gender on UKA outcomes has been assessed [15,19]. However, findings of such studies often lack significance because of small sample sizes and relatively low proportion of UKA among all knee arthroplasties. A meta-analysis can provide clarity in such situations but, to our knowledge, no meta-analysis has been performed to assess the role of these

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criteria on medial UKA outcomes. This is of particular interest as modern surgical techniques and implants now result in 5-, 10-, and 15-year medial UKA survivorship of 94%, 92%, and 89%, respectively, [10] whereas traditional criteria were established more than 25 years ago in response to data reporting 6-year survivorship of 70% [2].

Therefore, goal of this study was to assess the role of these selection criteria (ie, age, obesity, preoperative PFOA presence, ACL deficiency, and gender) on outcomes of medial UKA by assessing functional outcomes and revision rates in these groups. The hypothesis of this study was that with the modern surgical techniques and implants, some traditional exclusion criteria are no longer contraindications for medial UKA.

Methods

Search Strategy and Criteria

In the electronic databases PubMed, EMBASE, and Cochrane Library a systematic search was performed for studies reporting functional outcomes or survivorship of medial UKA on January 8, 2016. BASE and OpenGrey were searched for unpublished articles to minimize publication bias. Five different search algorithms were used (Table 1). The search results were combined, and after removing duplicates, 2 authors (JPL and HC) independently scanned all identified studies for eligibility by title and abstract. Selected studies were then scanned by full-text on the inclusion and exclusion criteria. National registries and article reference lists were scanned for additional data. When disagreement occurred between the 2 authors, a third author (HAZ) was consulted. Final consensus was reached with regard to inclusion and exclusion of all articles.

Inclusion and Exclusion Criteria

Inclusion criteria consisted of English-language studies that (1A) reported number of UKA and failed UKA or (1B) number of UKA and functional outcomes, (2) were comparative studies stratifying study population by age, gender, BMI, PFOA status, and/or ACL status, (3) were published between 2000 and 2016, (4) were reporting medial UKA or mainly medial UKA procedures, and (5) were minimum level-IV studies per the adjusted Oxford Centre for Evidence-Based Medicine level of evidence [20]. Exclusion criteria consisted of studies (1) having different indications for UKA than OA, (2) not reporting outcomes or failures by subgroups (ie, age, gender, BMI, PFOA, or ACL status), (3) using the same database, (4) only reporting UKA outcomes in 1 of 2 groups (eg, only age <60 years or >60 years), (5A) functional outcomes without mean score, standard deviation or number of patients, or (5B) reporting revision rates without follow-up (all required for analysis).

Table 1
Search Algorithms for 4 Independent Searches.

Age	([{unicondylar OR unicompartmental OR partial} AND {knee arthroplasty}] OR UKA) AND (age OR old OR young)
Gender	([{unicondylar OR unicompartmental OR partial} AND {knee arthroplasty}] OR UKA) AND (gender OR sex)
BMI	([{unicondylar OR unicompartmental OR partial} AND {knee arthroplasty}] OR UKA) AND (BMI OR weight OR overweight OR obes*)
PFOA	([{unicondylar OR unicompartmental OR partial} AND {knee arthroplasty}] OR UKA) AND (patellofemoral OR patell* OR PFJ)
ACL	([{unicondylar OR unicompartmental OR partial} AND {knee arthroplasty}] OR UKA) AND (ACL OR anterior cruciate ligament)

ACL, anterior cruciate ligament; BMI, body mass index; PFOA, patellofemoral osteoarthritis; UKA, unicompartmental knee arthroplasty.

Table 2
Quality Assessment of the Included Studies Using the Methodological Index for Nonrandomized Studies (MINORS) [21].

Study	1	2	3	4	5	6	7	8	9	10	11	12	Total
Beard et al [22]	2	2	2	1	0	2	0	2	2	2	0	2	17
Berend et al [23]	2	2	0	1	0	1	0	2	1	2	0	2	13
Boisseneault et al [24]	2	2	1	1	0	2	0	0	2	2	0	2	15
Cavaignac et al [25]	2	2	0	2	0	2	1	0	1	2	0	2	14
Collier et al	2	1	0	1	0	1	0	0	2	2	0	1	10
Dervin et al [26]	2	2	0	1	0	2	2	0	2	2	0	1	14
Engh et al [27]	2	2	0	2	0	2	0	0	2	2	0	2	14
Forsythe et al [28]	2	2	0	1	0	1	1	0	2	2	0	1	12
Hamilton et al [29]	2	2	0	1	0	2	0	0	2	2	0	2	13
Hernigou et al [30]	2	2	0	2	0	2	0	0	2	2	0	2	14
Heyse et al [31]	2	2	0	1	0	2	0	0	2	2	0	2	13
Hooper et al [32]	2	2	2	2	0	2	0	0	2	2	1	2	17
Ingale et al [33]	2	2	0	2	0	2	0	0	2	2	0	2	14
Jahromi et al [34]	2	2	0	2	0	2	0	0	2	2	0	1	13
Kristensen et al [35]	2	2	0	1	0	2	0	0	2	2	0	1	12
Lustig et al [36]	2	2	0	2	0	2	1	2	2	2	1	2	18
Mofidi et al [37]	2	2	0	2	0	2	2	0	2	2	0	2	16
Murray et al [38]	2	2	2	2	0	2	2	2	2	2	0	2	20
Naal et al [39]	2	2	0	2	0	2	0	0	2	2	1	2	15
Niinimaki et al [40]	2	2	0	2	0	2	0	0	2	2	1	1	14
Pandit et al [16]	2	2	2	2	0	2	0	0	2	2	0	2	16
Panni et al [41]	2	2	2	2	0	2	2	0	2	2	1	2	19
Plate et al [42]	2	2	0	1	0	2	0	2	2	2	1	2	16
Price et al [43]	2	2	0	1	0	2	0	0	2	2	2	1	14
Seyler et al [44]	2	2	0	1	0	2	0	0	2	2	1	1	13
Song et al [45]	2	2	2	2	0	2	0	0	2	2	0	2	16
Tabor et al [46]	2	2	0	2	0	2	0	0	2	2	0	2	14
Thompson et al [15]	2	2	0	2	0	2	0	0	2	2	0	1	13
Venkatesh et al [47]	2	2	0	2	0	2	0	0	2	2	0	2	14
White et al [48]	2	2	2	2	0	2	1	0	2	2	0	1	16
Wong et al [49]	2	2	0	1	0	2	0	0	2	2	0	1	12

The criteria of MINORS [21] with 0 points when not reported, 1 when reported but not adequate, and 2 when reported and adequate. Maximum score is 24.
1. A clearly stated aim: the question addressed should be precise and relevant in the light of available literature.
2. Inclusion of consecutive patients: all patients potentially fit for inclusion (satisfying the criteria for inclusion) have been included in the study during the study period (no exclusion or details about the reasons for exclusion).
3. Prospective collection of data: data were collected according to a protocol established before the beginning of the study.
4. End points appropriate to the aim of the study: unambiguous explanation of the criteria used to evaluate the main outcome which should be in accordance with the question addressed by the study. In addition, the end points should be assessed on an intention-to-treat basis.
5. Unbiased assessment of the study end point: blind evaluation of objective end points and double-blind evaluation of subjective end points. Otherwise the reasons for not blinding should be stated.
6. Follow-up period appropriate to the aim of the study: the follow-up should be sufficiently long to allow the assessment of the main end point and possible adverse events.
7. Loss to follow-up less than 5%: all patients should be included in the follow-up. Otherwise, the proportion lost to follow-up should not exceed the proportion experiencing the major end point.
8. Prospective calculation of the study size: information of the size of detectable difference of interest with a calculation of 95% CI, according to the expected incidence of the outcome event, and information about the level for statistical.
9. An adequate control group: having a gold standard diagnostic test or therapeutic intervention recognized as the optimal intervention according to the available published data.
10. Contemporary groups: control and studied group should be managed during the same period (no historical comparison).
11. Baseline equivalence of groups: the groups should be similar regarding the criteria other than the studied end points. The absence of confounding factors that could bias the interpretation of the results.
12. Adequate statistical analyses: whether the statistics were in accordance with the type of study with calculation of CIs or relative risk.

Quality Assessment of Studies

Level of evidence for all studies was determined using the adjusted Oxford Centre for Evidence-Based Medicine 2011 levels of evidence [20]. The methodologic quality of the individual studies was then assessed using the Methodological Index for Non-Randomized Studies (MINORS) instrument [21]. This instrument is designed to assess the study quality of individual nonrandomized comparative studies as were included in this meta-analysis. The results of grading according to MINORS instrument are displayed in Table 2. Finally, the Grades of Recommendation, Assessment, Development, and Evaluation (GRADE) [50] criteria were used to assess the overall quality of included studies and strength of recommendation. Two authors (*** and ***) assessed all studies with any disagreement mediated by a third author (***). Consensus was reached for all studies.

Data Collection

All data were collected in a datasheet in Excel 2011 (Microsoft Corp, Redmond, WA). Collected parameters included study authors, year of publication, subgroups reported, total number of UKA procedures, total number of failures, and reported functional outcomes. Revision rates were corrected for the follow-up length by reporting the annual revision rate (ARR). The ARR is the number of failures per 100 observed component years and is a method which is commonly used in orthopedic studies [51-53]. The observed component years are calculated by multiplying the number of total observed knees by the mean follow-up in years. To calculate the ARR, the number of failures is divided by these observed component years. Then this final number is multiplied by 100 calculate the percentage. This final number represents the percentage of knees that fail annually.

It was noted that the most commonly used age cutoff was 60 years in cohort studies, whereas this cutoff was 55 years in registries. Age-stratified results were therefore analyzed separately based on the source. Most studies used a cutoff of 30 kg/m^2 for BMI because this is the threshold for obesity as defined by the World Health Organization [54]. If necessary, multiple BMI groups were combined into 2 groups (ie, <30 and >30 kg/m^2) and mean and standard deviation were calculated with weighting the means and using the square root of the pooled variance, respectively. Most used functional outcomes reported were Knee Society Score Knee Score, Knee Society Score Function Score, Oxford Knee Score, and Hospital for Special Surgery score. Outcomes were reported as odds ratios (OR) with 95% CIs.

Statistical Analysis

Statistical analysis was performed using Review Manager 5.3 (Nordic Cochrane Center, Copenhagen, Denmark). Continuous outcomes were used to compare functional outcome scores in younger vs older patients, males vs females, nonobesity vs obesity, absent PFOA vs present PFOA, and deficient ACL vs intact ACL using forest plots. Dichotomous outcomes were then used to compare ARRs between aforementioned groups. Random-effects model were used for all analyses [55]. Funnel plots were used to assess publication bias in any of the outcomes. Results were considered significant when $P < .05$.

Results

Search Results

After removing duplicates and reviewing title, abstract, and full-text of the articles, a total of 31 studies [15,16,22-49,56] and 6 registries or registry-based studies [13,57-61] were included (Fig. 1). Seventeen studies [16,22,28,31-34,36-39,41,43,45,47-49] reported functional outcomes in 17,147 patients, whereas 23 studies [15,16, 23-27,29-31,33,35-40,42-44,46,47,56] and 5 registries [13,57-60] reported revision rates in 24,182 patients and 261,290 patients, respectively.

Quality of Studies

Seven studies were level II prospective cohort studies [16,22,30,32,38,41,45], whereas most studies were level III or level IV retrospective observational studies [15,23-29,31,33-37,39,40, 42-44,46-49,56]. Using the MINORS instrument, an average score of 14.5 was graded out of a maximum of 24. None of the studies were blinded or randomized and almost none of the studies

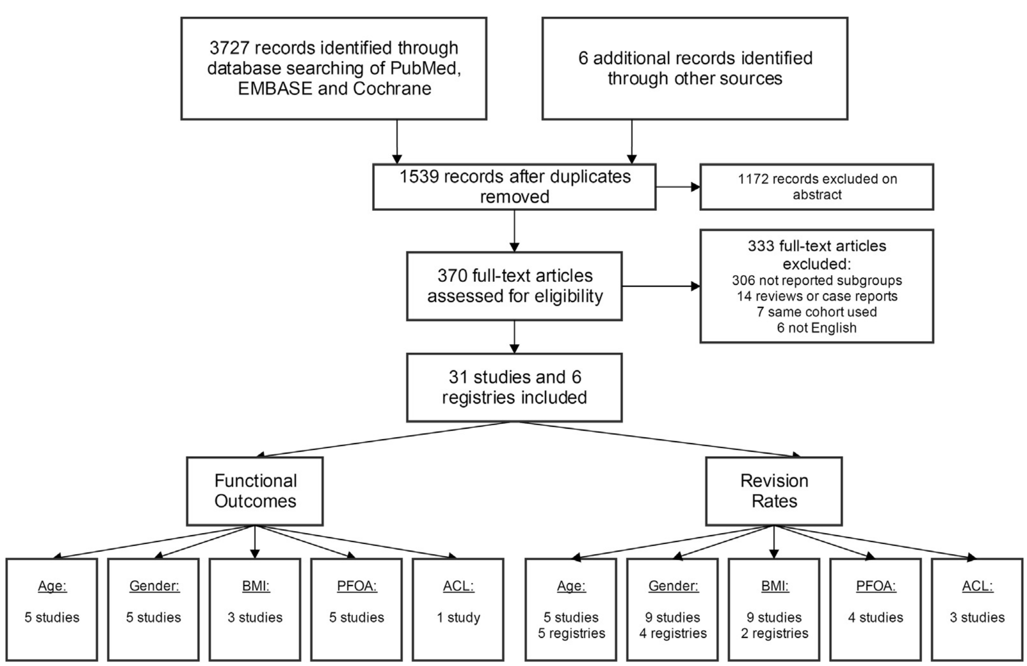

Fig. 1. Flow diagram of the search is shown. ACL, anterior cruciate ligament; BMI, body mass index; PFOA, patellofemoral osteoarthritis.

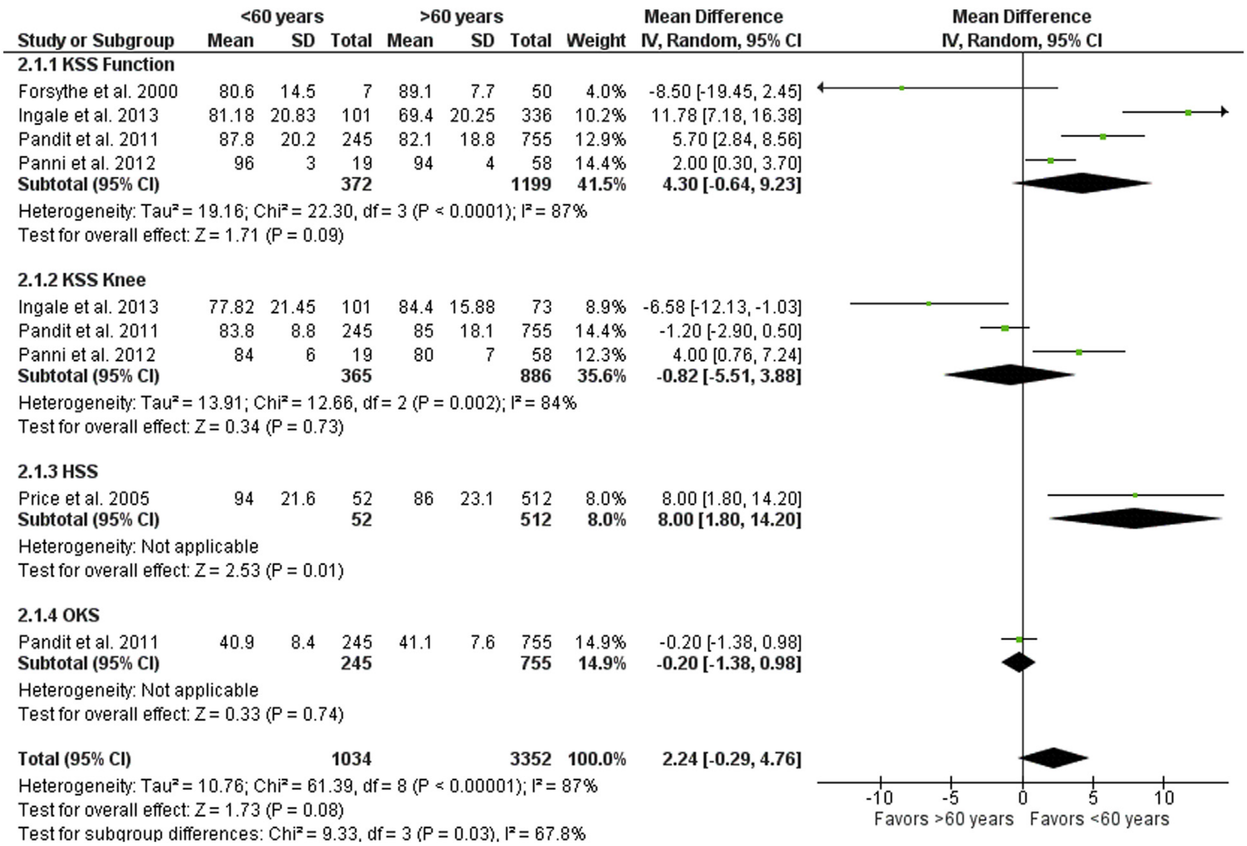

Fig. 2. Forest plots are shown of cohort studies reporting functional outcomes in patients younger and older than 60 years. HSS, Hospital for Special Surgery; KSS, Knee Society Score; OKS, Oxford Knee Score.

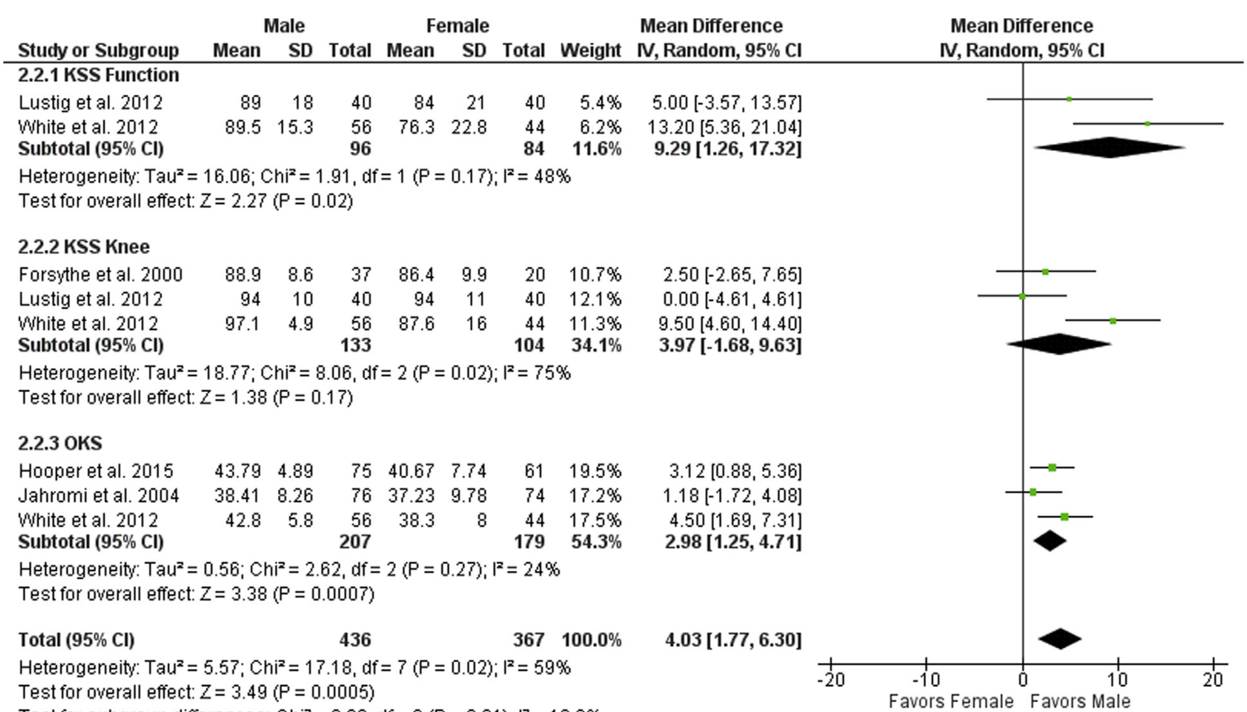

Fig. 3. Forest plots are shown of cohort studies and registries reporting functional outcomes in males and females.

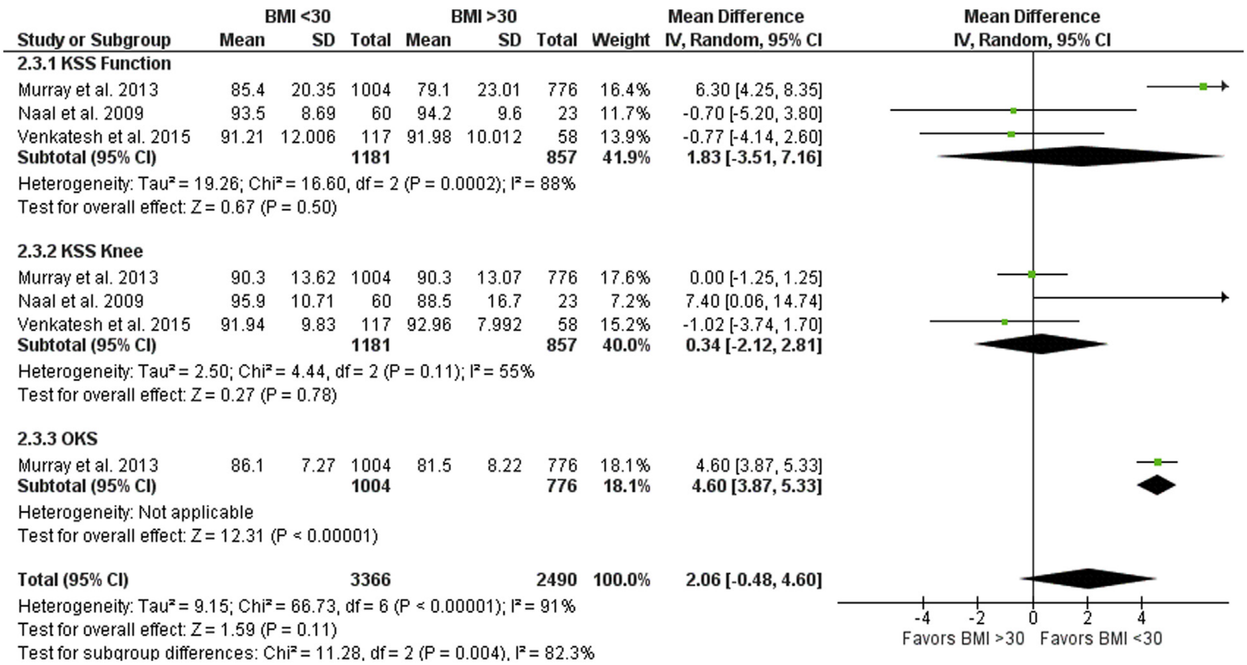

Fig. 4. Forest plots are shown of cohort studies reporting functional outcomes in nonobese and obese patients.

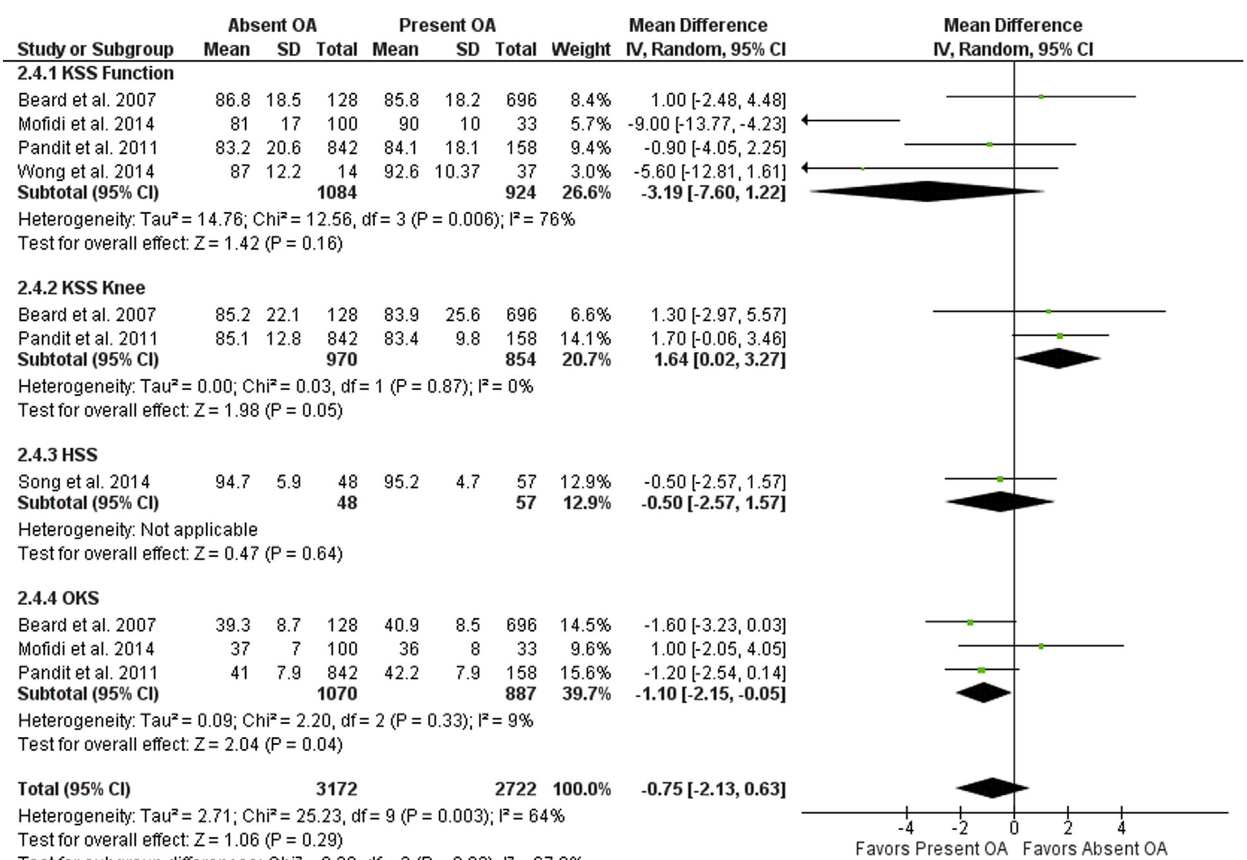

Fig. 5. Forest plots are shown of cohort studies reporting functional outcomes in patients with the presence or absence of preoperative patellofemoral osteoarthritis (OA).

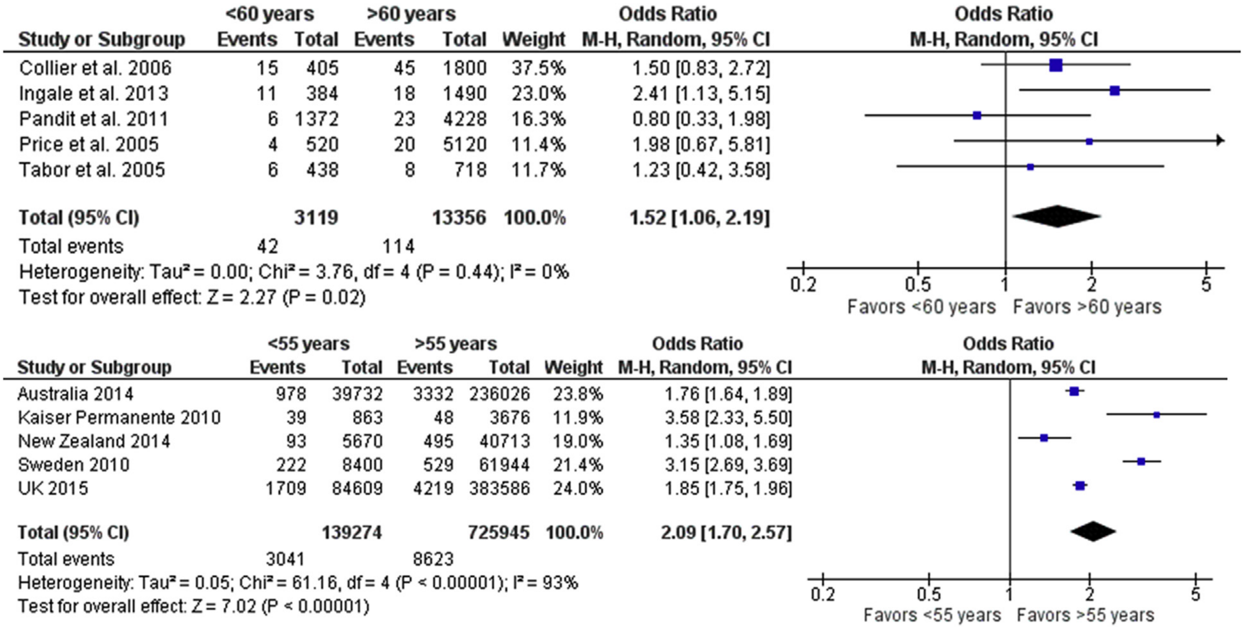

Fig. 6. Forest plots are shown of (Upper) cohort studies reporting UKA annual revision rates in patients younger and older than 60 years and (Lower) registries reporting UKA annual revision rates in patients younger and older than 55 years. The numbers in this figure represent the observed component years, which is calculated by multiplying the total observed knees by the mean follow-up in these specific groups. Using this method, there was a correction for differences in follow-up between both groups. UKA, unicompartmental knee arthroplasty.

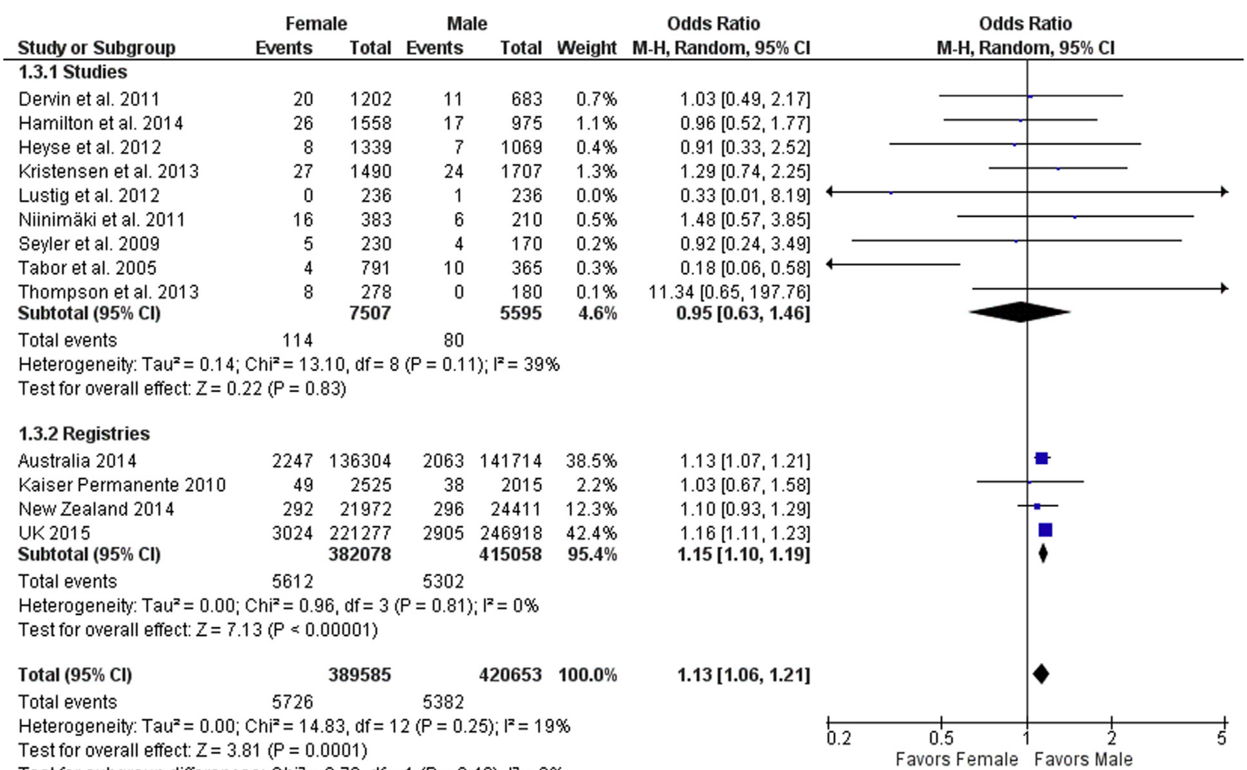

Fig. 7. Forest plots are shown of cohort studies and registries reporting UKA annual revision rates in males and females. The numbers in this figure represent the observed component years, which is calculated by multiplying the total observed knees by the mean follow-up in these specific groups. Using this method, there was a correction for differences in follow-up between both groups.

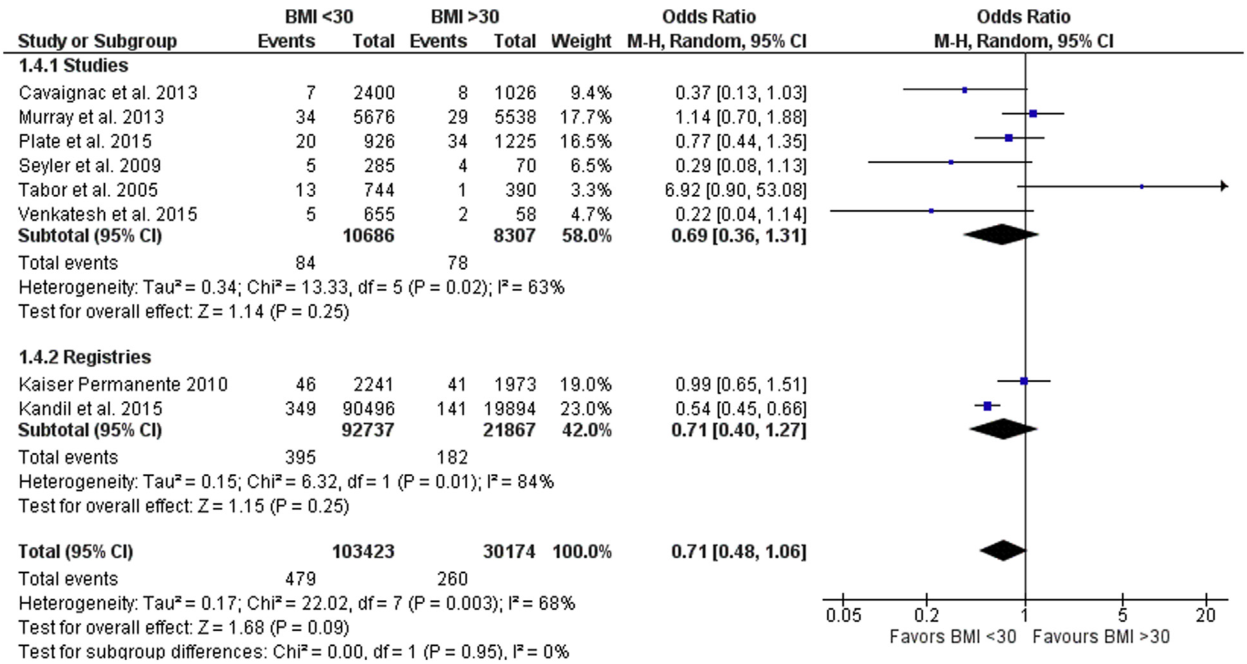

Fig. 8. Forest plots are shown of cohort studies and registries reporting UKA annual revision rates in nonobese and obese patients. The numbers in this figure represent the observed component years, which is calculated by multiplying the total observed knees by the mean follow-up in these specific groups. Using this method, there was a correction for differences in follow-up between both groups.

corrected for confounders (Table 2). Using the GRADE criteria, the overall quality of the studies and therefore strength of recommendation was low. No publication bias was detected in any of the analyses using funnel plots.

Functional Outcomes in Different Patient Groups

Analyzing 5 studies [16,28,33,41,43] that stratified outcome scores by age in 4386 patients, no significant differences between both groups were found, although a trend for better outcome scores in younger patients was noted (OR, 2.24; 95% CI, −0.29 to 4.76; $P = .08$; Fig. 2). Five studies [28,32,34,36,48] reporting outcomes in 807 patients showed significantly better outcomes in males than in females (OR, 4.03; 95% CI, 1.77-6.30, $P < .001$; Fig. 3). No significant better outcomes were found in nonobese patients in 3 studies [38,39,47] with 5856 patients (OR, 2.06; 95% CI, −0.48 to 4.60; $P = .11$; Fig. 4) or in patients without preoperative PFOA in 5 studies [16,22,37,45,49] with 5894 patients (OR, −0.75; 95% CI, −2.13 to 0.63; $P = .29$; Fig. 5). Finally, only one study [31] reported outcomes in 5 patients with ACL deficiency with 198 patients with an intact ACL and therefore no analysis was performed.

Revision Rates in Different Patients Groups

Pooled data in the different patients groups showed that in both cohort studies and registries, younger patients, females, and obese patients had higher ARR than older patients, males, and nonobese patients, respectively (Tables 3 and 4).

Analysis of 5 cohort studies [16,33,43,46,56] with 15,041 patients and 5 registries [13,57-60] with 126,346 patients showed increased likelihood for revision in younger patients (OR, 1.52; 95% CI, 1.06-2.19; $P = .02$ and 2.09; 95% CI, 1.70-2.57, $P < .001$, respectively; Fig. 6). Nine cohort studies [15,26,29,31,35,36,40,44,46] and 4 registries [13,58-60] reporting revision rates in 120,079 patients showed an increased risk for revision in females compared to males (OR, 1.13 [1.06-1.21]; $P < .001$; Fig. 7). Analysis of 6 cohort studies [25,38,42,44,46,47] and 2 registries [60,61] comparing revision rates in 21,204 patients only showed a trend of increased likelihood for revision in obese patients (OR, 0.71 [0.48-1.06]; $P = .09$; Fig. 8). Analyzing 4 studies [16,23,37,44] assessing revision rates in 1842 patients, revealed no increased risk for revision in patients with the presence of PFOA (OR, 0.63 [0.19, 2.12]; $P = .46$; Fig. 9). Finally, 3 studies [24,27,30] reported revision rates in 960 patients and no increased likelihood for revision could be detected in patients with ACL deficiency (OR, 0.86 [0.45-1.66]; Fig. 10).

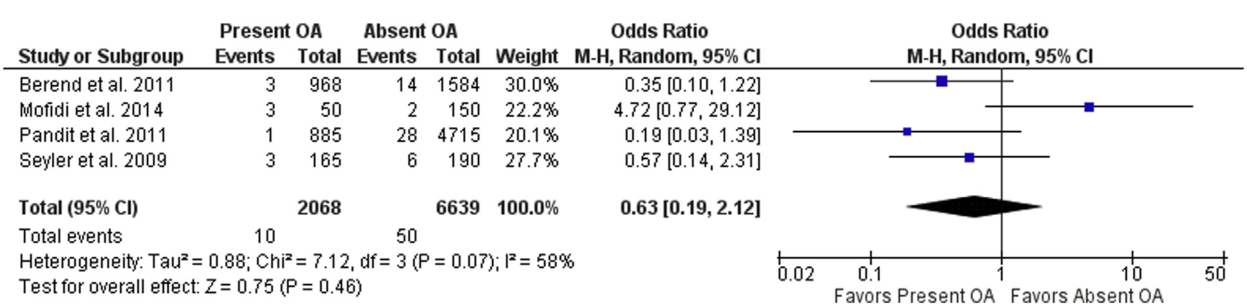

Fig. 9. Forest plots are shown of cohort studies reporting UKA annual revision rates in patients with the presence or absence of preoperative patellofemoral OA.

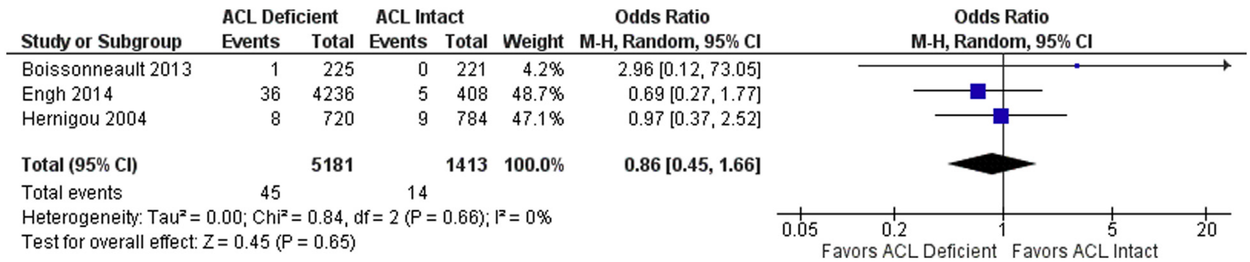

Fig. 10. Forest plots are shown of cohort studies reporting annual revision rates in patients with ACL deficiency or competency. The numbers in this figure represent the observed component years, which is calculated by multiplying the total observed knees by the mean follow-up in these specific groups. Using this method, there was a correction for differences in follow-up between both groups.

Discussion

Main findings of this meta-analysis were that (1) younger age is associated with an increased likelihood of revision and (2) female gender is associated with an increased likelihood of revision and inferior functional outcomes. Although not statistically significant, trends were noted toward superior functional outcomes in younger patients and toward higher revision rates in obese patients. The presence of PFOA and ACL deficiency was not associated with inferior outcomes.

Driven by unsatisfying functional outcomes [1] and revision rates up to 30% (an ARR of 5.30) [2], Kozinn and Scott proposed more strict patient selection criteria for UKA in their landmark article [3]. The authors published excellent results with these criteria, which led to adherence to the strict patient selection in the following years [4,62]. Over the years, implant designs and surgical techniques are improved, knowledge is increased and volume of UKA has increased, which has led to excellent revision rates and functional outcomes. Several authors therefore have challenged these traditional selection criteria [15,16,63]. We hypothesized that, with these developments, some strict traditional selection criteria are no longer contraindications for medial UKA and assessed this by comparing functional outcomes and revision rates of medial UKA in these patient groups.

With regard to functional outcomes, it was found that the traditional exclusion criteria of young age, obesity, presence of PFOA, and ACL deficiency were not associated with inferior outcomes. To the contrary, a trend for better functional outcomes was seen in younger patients. This may be explained by the fact that younger patients have high activity levels and high functional demands which are met by UKA. Patients with UKA have been shown to have a tendency to forget their artificial joint [64], recover quick from surgery [65,66], and have excellent range of motion [67] and functional outcomes [68,69]. The fact that these activities can be performed with UKA may explain why young people report satisfying functional outcomes. Surprisingly, no differences in functional outcomes between nonobese and obese patients were noted. It has been suggested that obesity could increase the stress on the prosthesis and subsequently causes pain, which is a common cause of revisions [70,71], whereas others have suggested that obese patients exert less stress on their implants due to lower activity levels and therefore have less pain and problems with function [72]. Murray et al performed an extensive analysis on the functional outcomes in different BMI groups and could not find any relationship between obesity and functional outcomes in mobile-bearing UKA. It was suggested that fixed-bearing all-polyethylene tibial implant designs could cause pain in obesity because this design has high peak stress on the tibia [73-76]. Developments in fixed-bearing UKA of adding a metal backing [77-79] causes better distribution of peak stress on the entire tibia [74-76]. Based on the results of this study and maybe due to these developments, it seems that obesity does not play a significant role on functional outcomes of mobile bearing and fixed-bearing medial UKA with a BMI cutoff of 30 kg/m^2.

It was further expected that patients with preoperative PFOA would have inferior outcomes after UKA surgery [3], but this was

Table 3
Overview of the Annual Revision Rates of All Included Studies for This Meta-Analysis, Categorized by Different Patient Populations According to Cohort Studies (Above) and Registries (Below).

Group	Studies	Total Knees	Failed	Mean FU	ARR	Range
PFOA	[16,23,37,44]	466	10	4.4	0.48	0.11-6.06
No PFOA	[16,23,37,44]	1376	50	4.8	0.75	0.59-3.16
BMI <30	[25,26,29,38,39, 42,44,46,47]	1990	84	5.4	0.79	0.29-2.16
Deficient ACL	[24,27,30]	797	45	5.9	0.87	0.44-1.11
BMI ≥30	[25,26,29,38,39, 42,44,46,47]	1823	78	4.7	0.91	0.26-5.71
Intact ACL	[24,27,30]	163	14	5.5	0.99	0.00-1.23
Males	[15,26,29,31,35, 36,40,44,46]	1082	80	5.2	1.43	0.00-2.86
Age ≥60 y	[16,33,43,46,56]	13,381	1723	8.9	1.45	0.39-2.50
Females	[15,26,29,31,35, 36,40,44,46]	1444	114	5.2	1.52	0.00-4.17
Age <60	[16,33,43,46,56]	1660	300	8.4	2.16	0.44-3.70
Group	**Registries**	**Total Knees**	**Failed Knees**	**Mean FU**	**ARR**	**Range**
BMI <30	[60,61]	13,790	395	6.7	0.43	0.39-2.05
BMI ≥30	[60,61]	3601	182	6.1	0.83	0.71-2.08
Age ≥55 y	[13,57-60]	106,053	8623	6.8	1.19	0.85-1.41
Males	[13,58-60]	61,733	5302	6.7	1.28	1.18-1.89
Females	[13,58-60]	55,820	5612	6.8	1.47	1.33-1.94
Age <55 y	[13,57-60]	20,293	3041	6.9	2.18	1.64-4.52

Annual revision rate is calculated by (failed knees/[total knees × mean FU]) × 100.
ACL, anterior cruciate ligament; ARR, annual revision rate; BMI, body mass index; FU, follow-up; PFOA, patellofemoral osteoarthritis.

Table 4
Overview of Different Patient Groups With Their Functional Outcomes and Annual Revision Rates.

Parameters	Functional Outcomes	Annual Revision Rates	
	Cohort Studies	Cohort Studies	Registries
Age	Young[a]	Old	Old
Gender	Males	–	Males
BMI	–	–	Nonobese[a]
PFOA	–	–	[b]
ACL	[b]	–	[b]

The named groups are the populations with superior outcomes.
–, no differences between both groups.
ACL, anterior cruciate ligament; BMI, body mass index; PFOA, patellofemoral osteoarthritis.
[a] It indicates that a trend is seen (P value between .05 and .10).
[b] It indicates not enough data are available in literature or registries.

not found in this present study. Similarly, other studies also did not find this relationship [18,72], which could be explained by the fact that some PFOA is a consequence of lower leg malalignment, commonly seen in unicompartmental OA [80] and that restoring this alignment during UKA can improve patellofemoral alignment and unloads the patellofemoral damaged articular cartilage [18,72]. Thein et al [18] even found better functional outcomes in patients with more severe PFOA showing that the PF joint congruence indeed significantly improved after medial UKA with the suggestion that this improved congruence leads to less contact forces over the PF joint.

Interestingly, it was noted that gender played a role on functional outcomes after UKA surgery. Liddle et al [19] found inferior outcomes of UKA in female gender in a large registry analysis and suggested that this may be caused by a technically more demanding procedure in females because of their smaller femoral condyles [81]. Chau et al [82] reported that more than 3-mm tibial component overhang is correlated with significantly worse Oxford Knee Score and pain scores than less than 3-mm overhang, and it has been suggested that this tibial overhang more frequently occurs in females because of their smaller femoral condyle [48] and thus leads to inferior outcomes and pain [82]. In TKA, similar findings have been reported, and the role of gender-specific implant designs have been discussed [83-86], whereas this has not yet been discussed in UKA literature. The results of this meta-analysis suggest that further research into the role of gender and the potential of gender-specific designs is needed.

This study also assessed the role of the patient selection criteria on UKA revision. The results indicate a higher revision risk in younger patients and females, whereas no increased revision risk was found in obese patients or patients with PFOA or ACL deficiency. The increased revision risk in younger patients, which was found both in cohort studies (ARR 2.16 vs 1.45) and in registries (2.18 vs 1.19), could be a consequence of the higher activity levels in younger patients because this increases the risk for polyethylene wear and aseptic loosening [87-90]. Furthermore, it has suggested that younger patients have higher preoperative expectations and are therefore less likely to accept suboptimal results [72]. This is particularly pertinent for UKA, where a relatively lower threshold for revision exists when compared to TKA [91,92]. However, an ARR of 2.18 in younger patients may still be acceptable given our data that suggest that younger patients have impressive functional outcomes with the procedure as well as data that support high return to sports [93]. In addition, in young patients, UKA may delay the need for TKA or decrease the number of TKA revisions needed in a lifetime [94-96]. Finally, in young patients, UKA may be attractive because some studies have demonstrated that UKA-to-TKA revisions are easier than TKA-to-TKA revisions [97] and have lower incidence of infections [98].

Similar to functional outcomes, the data show that female gender is an increased risk for revision. Large registries were necessary to show differences in revision rate between both genders [13,19,58,59] because cohort studies were unable to detect a difference in revision rate between genders [46,72,99,100]. This phenomenon of higher revision rates in females has therefore not extensively described in the literature, although Thompson et al noted an “alarmingly high discovery” of female revision rate (6.5% vs 0% in males) and stated “the reason for this is poorly understood and warrants further investigation” [15]. The higher revision risk in female gender may be explained by implant sizing issues in females [81]; however, we feel further research is needed regarding this topic.

Obesity, ACL deficiency, and PFOA were not associated with increased revision risk. Murray et al [38] performed an extensive analysis on revision risk in different BMI groups in 2438 patients and could not find difference in revision rates between all groups although the number of revisions was small. Registries may therefore shine more light on the role of BMI on revision rates as they did for gender. Kandil et al [61] reported in their study, based on registry data from a Health Insurance database, that the revision rate in UKA was 2.7% for nonobese, 4.5% for obese, and 5.7% for morbidly obese patients at 7-year follow-up, which suggests that BMI may play a role in revision rates. A limitation of our data was that we could not analyze the effect or morbid obesity on UKA and had to limit our study to patients with BMI greater than or less than 30. Indeed, morbid obesity may well affect survivorship after UKA as Kandil et al reported [61]. Therefore, it would be of value if future registries would report BMI data to assess the role of BMI on revision rates.

ACL deficiency was historically considered as a contraindication because ACL deficiency can lead to more posterior wear patterns [101,102], increased risk for aseptic loosening and increased polyethylene wear [24,27,103]. Therefore, simultaneous ACL reconstruction with UKA surgery has been performed [104-106]. The data in this study, however, did not show an increased revision rate with ACL deficiency, and it remains unclear if simultaneous ACL reconstruction is necessary. With regard to PFOA, no increased revision risk could be found in this analysis. The rationale behind this is similar as discussed with the functional outcomes. Similarly, Kuipers et al [72] performed a large analysis of 437 patients and could not identify PFOA as a risk factor for revision. They also concluded that correcting the malalignment in medial OA will improve patellofemoral alignment and unloads the damaged PF articular cartilage. Based on the results in this study, PFOA and ACL deficiency do not seem to be correlated with inferior outcomes after medial UKA while a trend for increased risk with obesity was seen.

Limitations are present in this study. First, studies were selected on the basis of uniform cutoff values (ie, age 55 and 60 years and BMI 30 kg/m^2) and only studies reporting both groups (eg, age younger than 60 years and older than 60 years) were included. Therefore, not all studies could be included [14,15,107,108]. However, only including comparative studies reduced the risk for bias. Second, studies that did not provide mean values, standard deviations, or group sizes were not conducive to comparative analysis and could not be included, which limited the number of entries. Third, the included cohort studies were mostly performed at high-volume centers and therefore the results may not be extrapolated to low-volume centers. However, registries were included in this study, which also include low-volume centers, and these data were more generalizable. Fourth, heterogeneity was present in the studies reporting the presence of PFOA. However, all studies ultimately used a binary classification of “present or absent OA,” and therefore, these studies were included. Finally, the quality of the included studies was low according to GRADE criteria and scored 14.5 of 24 according to MINORS criteria. It was noted that almost none of the studies corrected for confounding factors such as BMI, age, gender, and preoperative outcome scores.

In conclusion, this meta-analysis on UKA outcomes using traditional patient selection criteria showed an increased revision risk in patients younger than 60 years and an increased likelihood of revision along with inferior functional outcomes in females. No differences in functional outcomes or revision rates could be detected in obese patients, patients with preoperative PFOA, or ACL deficiency. These findings suggest that the historical strict patient selection criteria, as proposed by Kozinn and Scott, are no absolute contraindications with modern surgical techniques and implant designs. Knowledge of outcomes in different subgroups may help the orthopedic surgeon in managing patient expectations.

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