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Review

# Annual revision rates of partial versus total knee arthroplasty: A comparative meta-analysis

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ABSTRACT

*Background:* Utilization of unicompartmental knee arthroplasty (UKA) and patellofemoral arthroplasty (PFA) as alternatives to total knee arthroplasty (TKA) for unicompartmental knee osteoarthritis (OA) has increased. However, no single resource consolidates survivorship data between TKA and partial resurfacing options for each variant of unicompartmental OA. This meta-analysis compared survivorship between TKA and medial UKA (MUKA), lateral UKA (LUKA) and PFA using annual revision rate as a standardized metric.
*Methods:* A systematic literature search was performed for studies quantifying TKA, MUKA, LUKA and/or PFA implant survivorship. Studies were classified by evidence level and assessed for bias using the MINORS and PEDro instruments. Annual revision rates were calculated for each arthroplasty procedure as percentages/observed component-year, based on a Poisson-normal model with random effects using the R-statistical software package.
*Results:* One hundred and twenty-four studies (113 cohort and 11 registry-based studies) met inclusion/exclusion criteria, providing data for 374,934 arthroplasties and 14,991 revisions. The overall evidence level was low, with 96.7% of studies classified as level III–IV. Annual revision rates were lowest for TKA (0.49%, CI 0.41 to 0.58), followed by MUKA (1.07%, CI 0.87 to 1.31), LUKA (1.13%, CI 0.69 to 1.83) and PFA (1.75%, CI 1.19 to 2.57). No difference was detected between revision rates for MUKA and LUKA ($p = 0.222$).
*Conclusions:* Revisions of MUKA, LUKA and PFA occur at an annual rate of 2.18, 2.31 and 3.57-fold that of TKA, respectively. These estimates may be used to inform clinical decision-making, guide patient expectations and evaluate the cost-effectiveness of total versus partial knee replacement in the setting of unicompartmental OA.



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## 1. Introduction

Partial knee arthroplasty (PKA) has undergone a renaissance over the past two decades for the treatment of unicompartmental knee osteoarthritis (OA) [1–3]. Based on the principle of selective resurfacing while sparing healthy bone and ligaments, PKA encompasses (1) medial unicompartmental knee arthroplasty (UKA), (2) lateral UKA and (3) patellofemoral arthroplasty (PFA) [2,4]. Short-term advantages of PKA include decreased blood loss, shorter operative times, lower complication rates and faster postoperative rehabilitation compared to total knee arthroplasty (TKA) [1,5–7]. In the long term, PKA provides greater range of motion (ROM) and higher rates of return to sports with preserved native kinematics and proprioception [2,5,6,8–13]. PKA has become increasingly popular as an alternative to TKA following improved survivorship reports (resulting from updated implant designs, surgical techniques and patient selection criteria) [2,4,14,15].

This represents a shift in the management philosophy of knee OA from a 'one size fits all' solution to a tricompartmental 'hub and spoke' model, in which PKA presents a joint-preserving option where indicated (Figure 1) [1–3,7]. To guide this clinical decision, a need exists for comparative survivorship data between TKA and corresponding partial resurfacing options for all variants

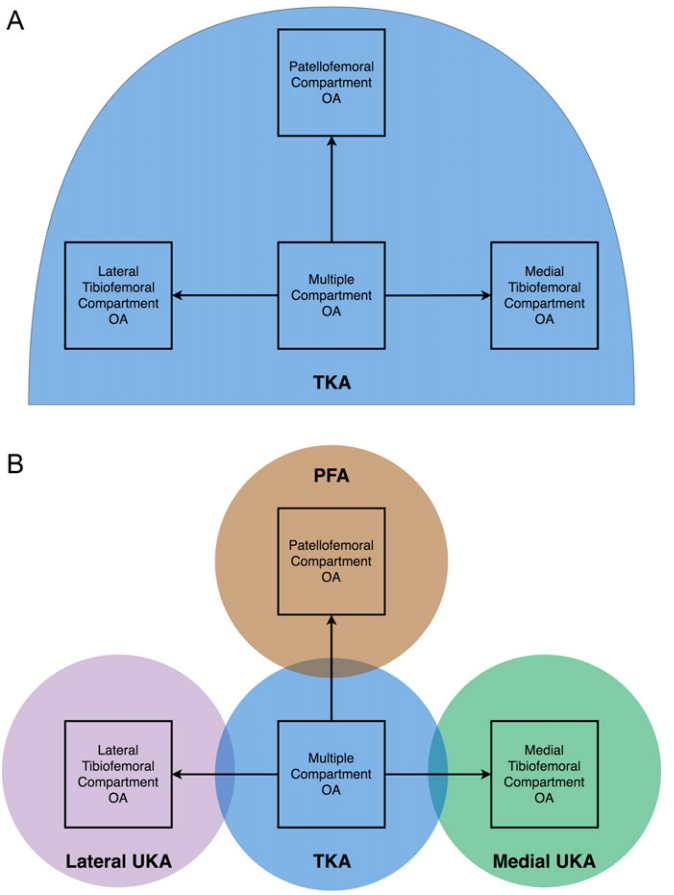


**Figure 1.** Compartmental approach to knee arthroplasty. Past versus present management approaches for isolated unicompartmental knee OA. Historically, the entire joint was replaced regardless of degenerative pattern (A). Under the modern tricompartmental model, only the diseased compartment is resurfaced for patients who qualify (B). Abbreviations: *TKA*, total knee arthroplasty; *UKA*, unicompartmental (tibiofemoral) arthroplasty; *PFA*, patellofemoral arthroplasty; *OA*, osteoarthritis.

of unicompartmental knee OA. To date, no single resource provides this information. Meta-analyses comparing UKA to TKA do not distinguish between medial and lateral subtypes, despite evidence that these comprise two very different procedures [16–21]. No meta-analysis or randomized clinical trials (RCT) comparing PFA and TKA survivorship exist [22]. Registries contain data for all such procedures but reflect the implants and techniques of a single nation, limiting generalizability. Combining findings from different sources is not possible, as survivorship is expressed non-uniformly with metrics ranging from cumulative failure to hazard ratios.

We performed a meta-analysis to create a comprehensive resource for survivorship data between TKA and each PKA alternative under the tricompartmental 'hub and spoke' model. Our objective was to permit direct comparison of annual revision rates between TKA and medial UKA (MUKA), lateral UKA (LUKA) or PFA for each variant of unicompartmental OA. This represents the first effort to consolidate survivorship data for all PKA subtypes against the existing standard of treatment.

## 2. Methods

### *2.1. Search strategy*

A systematic literature search was performed in the PubMed, EMBASE and Cochrane Library databases on October 12, 2015 to identify studies reporting survivorship data for TKA, MUKA, LUKA and PFA. The search terms consisted of '(total OR TKA OR TKR),' '(unicompartmental OR unicondylar OR UKA OR UKR),' and '(patellofemoral OR PFA OR PFR)' combined with '(knee arthroplasty OR knee replacement) AND (prosthesis OR implant) AND (failure OR revision OR reoperation OR survival OR survivorship)' across three parallel searches (Figure 2). Results were filtered to retrieve only English-language studies published in 2005 or later. Two authors (HC and JPL) independently screened all entries by title and abstract against the inclusion/exclusion criteria (Table 1). Studies selected then underwent full-text review (HC and JPL) against these criteria. A third author (HAZ) was consulted in the event of any disagreement. Consensus was ultimately achieved regarding the inclusion/exclusion of all studies reviewed. The search and data analysis was performed in accordance with PRISMA guidelines [23].

### *2.2. Data extraction*

Data describing (1) patient source (cohort or registry-based), (2) mean cohort age, (3) initial cohort size, (4) number of deaths with implant status unknown and/or losses to follow-up, (5) minimum follow-up duration, (6) mean follow-up duration, and (7) number of revisions was recorded in a spreadsheet (Excel 2008, Microsoft Inc., Redmond, WA) for all studies. Revision was defined as 'a new operation in a previously resurfaced knee during which one or more of the components are exchanged, removed or added,' per the Swedish Knee Registry [24]. Open reduction and internal fixation (ORIF) for periprosthetic fractures was counted towards this definition, as was subsequent patellar resurfacing.

Implant survivorship was reported as annual revision rate (expressed as percentage per observed component-year). This metric corrects for differential follow-up periods between populations, permitting direct comparison with a high degree of statistical accuracy [16,25]. All deaths with implant status unknown and losses to follow-up were subtracted from the initial population size,

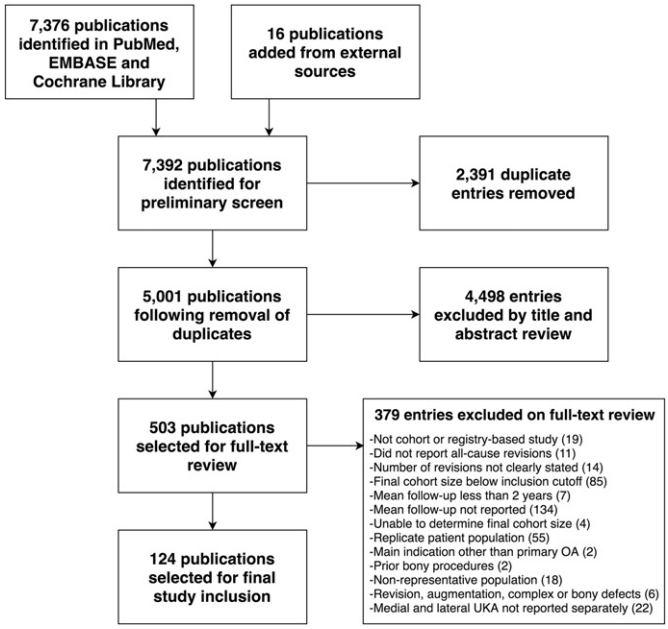


**Figure 2.** Systematic search algorithm. Systematic search algorithm performed per PRISMA guidelines.

**Table 1**
Inclusion and exclusion criteria.

| | |
|---|---|
| *Inclusion* | |
| 1 | Cohort or registry-based studies with TKA, UKA or PFA as index procedure |
| 2 | Primary osteoarthritis as the main indication for surgery |
| 3 | Reported mean postoperative follow-up time or total observed component-years |
| 4 | Reported total number and reasons for revision/reoperation |
| 5 | Minimum postoperative follow-up of two years |
| 6 | Minimum final population of 300 (TKA), 100 (medial UKA), 20 (lateral UKA) or 20 (PFA) |
| *Exclusion* | |
| 1 | Only included patients with specific pathology (i.e. hemophilia or morbid obesity) or demographic cutoff (i.e. only aged >65 or only female) not representative of the general population[a] |
| 2 | Only reported specific failure modes (e.g. revisions not "all-cause") |
| 3 | Only reported revisions/reoperations for a single component |
| 4 | Previous bony surgeries (e.g. high tibial osteotomy, tibial tubercle transfer, patellectomy) |
| 5 | Revision or complex primary procedures (e.g. involving augmentation or bony defects) |
| 6 | Duplicate or overlapping patient populations |
| 7 | Did not report cohort size, loss to follow-up and/or revisions/reoperations separately for medial and lateral UKA if combined patient population |

*TKA*, total knee arthroplasty; *UKA*, unicompartmental knee arthroplasty; *PFA*, patellofemoral arthroplasty. Where replicate patient data was detected (overlapping author/institution/registry, implant model and date range), the study with the greatest number of observed component-years was retained and redundant studies were excluded.

[a] Exclusion criteria 1 was applied to papers that included only subjects with a specific pathology or demographic. This was done to ensure homogeneity between the cohorts being compared. Subjects with these features were still present throughout the studies selected for inclusion, but only if part of a representative population as opposed to an isolated special population.

which was based on the number of eligible subjects minus any exclusions, deaths, or losses prior to minimum follow-up. The resulting final cohort size was multiplied by mean follow-up to estimate the total observed component-years [26]. Annual revision rates were generated for each study by dividing the total number of revisions by total observed component-years. Three studies did not report mean follow-up but provided at least two of the following: (1) total revisions, (2) total observed component-years or (3) net annual revision rate [25,27,28]. These values were manually input and used to calculate the missing values.

### 2.3. Statistical analysis

The total number of knee arthroplasties, revisions and observed component-years were extracted for each procedure category, stratified by cohort only or combined cohort and registry-based studies. Pooled annual revision rates were calculated for (A) all studies and (B) cohort studies only using a Poisson-normal model with random effects. Log incidence rates were back-transformed using exponentiation to obtain annual revision rates for TKA, MUKA, LUKA and PFA. These were reported as mean values with 95% confidence intervals (CI) [29]. Significance testing was performed via meta-regression with a normal-normal mixed effects model using TKA as the reference value at a threshold of $p < 0.05$. Additional significance testing was performed between MUKA and LUKA annual revision rates. All statistical analysis was performed using R version 3.2.3 (R Foundation for Statistical Computing, Vienna, Austria) with Metafor version 1.9-8 (Maastricht University, Maastricht, Netherlands).

### 2.4. Heterogeneity and risk of bias assessment

All studies included were assessed for methodological, clinical and statistical heterogeneity. Methodological heterogeneity was evaluated concurrently with risk of bias by rating the evidence level and methodological quality of each publication, as this accounts for specific aspects of study design. This was done independently by two authors (HC and MRS), with any disagreements referred to a third author (JPL) and discussed until consensus was reached. Levels of evidence were based on the definitions published by the Center for Evidence-Based Medicine [30]. Quality assessment was performed with the PEDro (Physiotherapy Evidence Database) or MINORS (Methodological Index for Non-Randomized Studies) instruments. The former contains 11 items of which 10 are counted, and was applied to RCT [31]. The MINORS scale consists of eight items (with four supplementary items for comparative studies), and was used to assess non-randomized studies [32]. Clinical heterogeneity was evaluated by comparing the mean patient age between each arthroplasty cohort. This was reported as the mean and standard deviation weighted by final cohort size. Other patient variables were not compared due to inconsistency in how these were reported between studies. Statistical heterogeneity was assessed using the $I^2$ statistic with thresholds of 25% (low heterogeneity), 50% (moderate heterogeneity) and 75% (high heterogeneity).

## 3. Results

### 3.1. Search results

A total of 124 publications were selected for inclusion after full-text review (Figure 2). Three sources provided data for multiple procedures (two MUKA and LUKA, one TKA and PFA) [25,27,33], yielding 127 unique data entries in total. Fifty-two entries

**Table 2**
Study and population statistics.

| | Mean age (Y) | Knees | Revisions | Component-years |
|---|---|---|---|---|
| *Cohort and registry-based* | | | | |
| TKA | 69.4 ± 1.6 | 333,727 | 12,907 | 2,058,368.7 |
| Medial UKA | 65.8 ± 2.7 | 38,742 | 1851 | 154,238.0 |
| Lateral UKA | 65.0 ± 5.0 | 968 | 73 | 5135.9 |
| PFA | 59.7 ± 5.7 | 1497 | 160 | 8412.1 |
| *Cohort only* | | | | |
| TKA | 68.6 ± 2.2 | 54,777 | 2145 | 435,178.3 |
| Medial UKA | 67.4 ± 4.0 | 14,647 | 800 | 79,738.1 |
| Lateral UKA | 65.0 ± 5.0 | 968 | 73 | 5135.9 |
| PFA | 59.4 ± 6.4 | 1205 | 140 | 7282.9 |

*TKA*, total knee arthroplasty; *UKA*, unicompartmental knee arthroplasty; *PFA*, patellofemoral arthroplasty; *Y*, years.

were recorded for TKA [25,34–84], 37 for MUKA [27,28,33,85–118], 13 for LUKA [27,33,119–129] and 25 for PFA [25,130–153]. A total of 113 cohort studies (115 entries) [27,33–39,41–50,52–58,60–72,76,78,79,81–99,101–153] and 11 registry-based studies (12 entries) [25,28,40,51,59,73–75,77,80,100] were included.

### 3.2. Annual revision rates

The combined studies provided data for a total of 374,934 knee arthroplasties and 14,991 revisions. Subject age, total knees, total revisions and total component-years by procedure and study type are provided in Table 2. Combined cohort and registry-based data showed that annual revision rates were lowest for TKA (0.49%, CI 0.41 to 0.58), followed in order by MUKA (1.07%, CI 0.87 to 1.31), LUKA (1.13%, CI 0.69 to 1.83) and PFA (1.75%, CI 1.19 to 2.57) (Table 3) (Figures 3–5). No difference was detected between annual revision rates of MUKA and LUKA ($p = 0.222$). Following stratification to include only cohort-based data, a slight decrease was noted in the annual revision rates of TKA, MUKA and PFA (Table 4). Similarly, no significant difference was observed between MUKA and LUKA annual revision rates ($p = 0.217$).

### 3.3. Heterogeneity and risk of bias

One level I RCT was included [64]. Two publications were level II prospective studies [58,103]. Thirty-three studies [27,28,40,46–48,51,53,56,59,61,65,71,72,74,77,78,81,84,86,97,98,103,104,106,109,118,122,124,125,138,140,143] were level III retrospective studies and 87 [33–39,41–45,49,50,52,54,55,57,60,63,66–70,73,75,76,79,80,82,83,85,87–96,99–102,105,107,108,110–117,119–121,123,126–137,139,141,142,144–153] were level IV case series, with one registry report ineligible for grading [25]. The RCT was awarded seven points on the PEDro scale, satisfying 70% of the criteria [64]. Thirty-five non-randomized comparative (levels II and III) studies scored a mean of 18.5 Standard deviation (SD 2.4) on the MINORS instrument, corresponding to 77.1% of the maximum possible. Eighty-seven non-randomized non-comparative (level IV) studies scored a mean of 10.8 (SD 1.2) on the MINORS scale, representing 67.4% of the maximum points possible. Statistical heterogeneity was high among the TKA, MUKA and PFA studies and moderate to high for the LUKA studies in both the combined and cohort-only analyses (Tables 3–4).

## 4. Discussion

Our study synthesized clinical data from the past decade to compare implant survivorship for TKA versus PKA in all scenarios. Revision of MUKA (1.07%), LUKA (1.13%) and PFA (1.75%) was 2.18, 2.31 and 3.57-fold more frequent than revision of TKA (0.49%), respectively (Figures 3–5). This represents the first population-level comparison of such revision rates under the tricompartmental model, using a time-independent metric.

Several explanations exist for the lower survivorship of UKA compared to TKA. First, UKA is highly sensitive to technical parameters such as mechanical alignment [154,155]. Overcorrection induces degeneration of the contralateral compartment, leading to revision [156]. Second, definitions of aseptic loosening (which constitutes 25% of early failures) are inconsistent and user-dependent

**Table 3**
Comparative annual revision rates of cohort and registry-based studies.

| | TKA | Medial UKA | Lateral UKA | PFA |
|---|---|---|---|---|
| Studies included | 52 | 37 | 13 | 25 |
| Annual revision rate | 0.49 | 1.07 | 1.13 | 1.75 |
| Confidence interval (95%) | 0.41–0.58 | 0.87–1.31 | 0.69–1.83 | 1.19–2.57 |
| *p*-Value | Reference | <0.001 | <0.001 | <0.001 |
| $I^2$ (%) | 98.67 | 92.50 | 65.97 | 79.89 |

*TKA*, total knee arthroplasty; *UKA*, unicompartmental knee arthroplasty; *PFA*, patellofemoral arthroplasty. Annual revision rate is expressed as the percentage of revisions per observed-component year. Significance testing was performed with meta-regression using TKA as the reference.

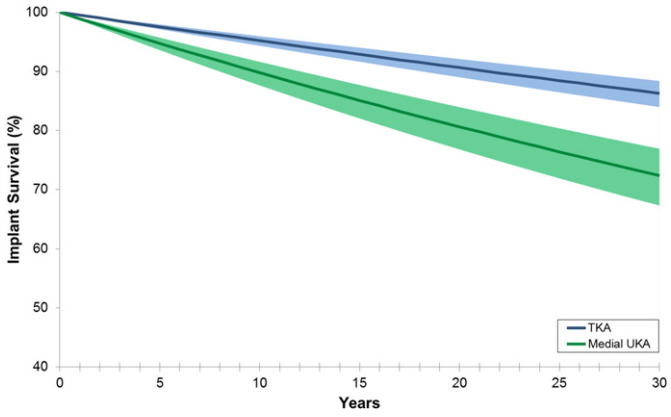


**Figure 3.** Predicted implant survivorship of TKA versus medial UKA. Projected cumulative implant survivorship of total knee arthroplasty (TKA) compared to medial unicompartmental knee arthroplasty (UKA) over an extrapolated period of 30 years. Transparent bands represent 95% confidence intervals.

[157]. Aseptic loosening is diagnosed by the presence of radiographic radiolucent lines (RLL) in the presence of postoperative pain [158]. Low-volume surgeons, however, may lack the experience to diagnose this phenomenon with specificity [158,159]. RLL are often physiologic, while residual pain can last for up to two years as tibial stresses redistribute [101]. Third, surgeons have a lower threshold to revise UKA due to the relative ease (versus primary TKA to revision TKA) and preserved bone stock [160]. Finally, OA progression comprises 40% of late UKA failures [157]. This reflects the natural history of a pathologic process rather than a mechanical shortcoming of the implant, affecting survivorship rates of UKA but not TKA.

Technological advances and policy initiatives may help UKA achieve survivorship parity with TKA. Robotic and navigated systems have shown promise in achieving narrow tolerances for key technical parameters [161,162]. However, long-term follow-up data is required. Preliminary outcomes of cementless UKA implants have also been encouraging, as these decrease the incidence of RLL that may prompt unnecessary revision in the presence of temporary pain [25,101]. At the policy level, several authors have endorsed the creation of regional UKA 'hubs' to decrease revision associated with low-volume facilities [163,164]. As implant durability continues to improve, UKA is likely to be increasingly regarded as a permanent rather than a temporizing alternative to TKA.

Notably, the data did not reveal significantly different annual revision rates between MUKA and LUKA. In recent years, research underscoring the kinematic and anatomic differences between the medial and lateral tibiofemoral compartments has led to these being regarded as two very distinct procedures [18–21]. Several authors have proposed that the lower volume and perception of LUKA as a more technically demanding procedure have contributed to its underutilization in favor of TKA [3,33,165]. A recent meta-analysis found no significant survivorship difference between MUKA and LUKA, with two cohort studies reaching similar conclusions [27,165,166]. Our study not only corroborates these findings with increased statistical power, but also provides a control baseline in the form of TKA revision rates obtained with identical methodology. This is particularly salient given the lack of any RCT comparing LUKA to TKA.

Higher revision rates for PFA may be explained by (1) non-uniform selection criteria, (2) implant design issues and (3) non-standardized surgical technique [7,15,167,168]. PFA lacks an equivalent to the 1989 Kozinn and Scott criteria, which decreased UKA revision rates through strict selection guidelines [2,169]. Tibiofemoral degeneration and/or malalignment are absolute contraindications for PFA given the risk of OA progression, with some authors suggesting that secondary OA (i.e. secondary to trochlear

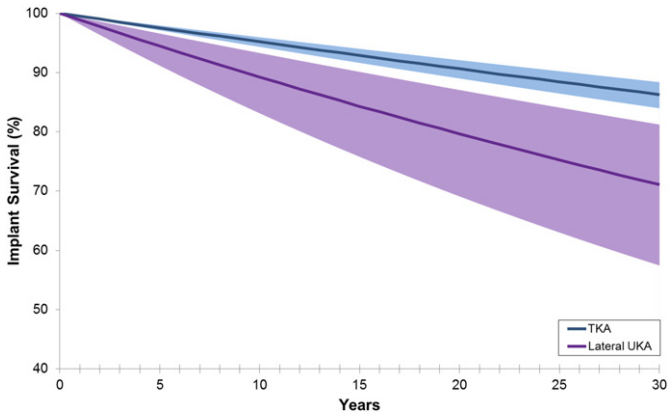


**Figure 4.** Predicted implant survivorship of TKA versus lateral UKA. Projected cumulative implant survivorship of total knee arthroplasty (TKA) compared to lateral unicompartmental knee arthroplasty (UKA) over an extrapolated period of 30 years. Transparent bands represent 95% confidence intervals.

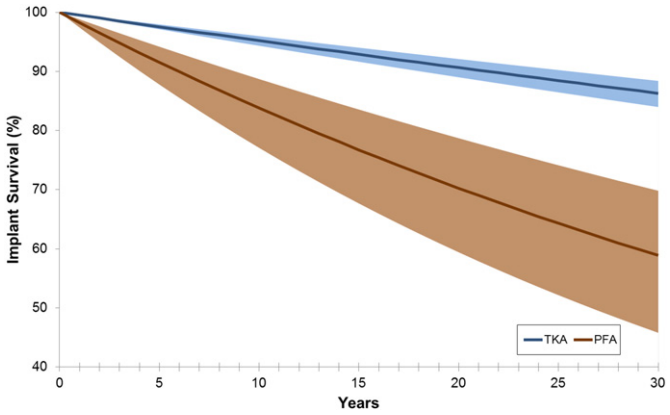


**Figure 5.** Predicted implant survivorship of TKA versus patellofemoral arthroplasty. Projected cumulative implant survivorship of total knee arthroplasty (TKA) compared to patellofemoral arthroplasty (PFA) over an extrapolated period of 30 years. Transparent bands represent 95% confidence intervals.

dysplasia, maltracking or trauma) represents a more suitable indication [135,147,167,170,171]. Gender-specific and customized implants are of particular interest in the development of third-generation PFA, with respect to minimizing maltracking and pain from soft-tissue impingement [150,172]. Intramedullary instrumentation (versus earlier freehand techniques) and robot-assisted techniques have also been shown to aid the precision and reproducibility of implant placement [140,150,172,173]. Second-generation PFA has already demonstrated a three to four-fold reduction in revision rates from earlier implants, rekindling interest in PFA as a means to delay TKA for young active patients [15,174].

The above findings have important implications for the surgical treatment of unicompartmental OA. Despite its high durability, TKA imposes significant functional and lifestyle restrictions secondary to the loss of ligaments and healthy bone stock [175,176]. Postoperative ROM is markedly better following PKA, particularly in flexion-dependent activities [5,9,10]. Subjects undergoing PKA report higher activity levels and return to sports versus those who receive TKA [6,11–13]. At the individual level, this is of particular importance to younger patients who may prefer PKA for its functional advantages despite the increased failure risk [2,174]. Annual revision rates permit direct comparison of this lifetime risk based on the age of the individual patient. At the policy level, the tradeoff between the clinical benefits of PKA against the higher risk of implant failure (with the associated costs and morbidity of revision TKA) determines the relative cost-effectiveness of such procedures [177,178]. As the US healthcare industry faces continuing pressure to demonstrate cost-efficiency, these time-independent failure rates may be applied to decision-analytic models quantifying the economics of selecting PKA over TKA [179].

This study has several limitations. First, no registry-based studies conforming to the inclusion/exclusion criteria provided survivorship data for LUKA [28]. As registry-based failure rates are typically higher than those of cohort studies, this may have the relative annual revision rates of LUKA [16]. However, subgroup analysis of cohort studies showed that this distinction had a negligible effect on the estimated rates for TKA, MUKA and PFA. Second, the overall quality of the studies selected was low with the majority of studies reporting level IV evidence. However, as no level I or II studies concerning LUKA or PFA have been published to date, the present study represents the best available effort to consolidate survivorship data across all four procedures [15,165,180]. Third, TKA studies were not matched to comparative PKA studies by indication (e.g. unicompartmental OA). This is unlikely to influence the findings or their clinical implications, however. PKA and TKA are generally subject to the same modes of failure, with the exception of multicompartmental OA progression [157,181]. The use of TKA obviates OA progression as an indication for revision, eliminating the ability to statistically differentiate between single or multicompartmental OA as the initial surgical indication. Finally, annual revision rates are known to inversely correlate with patient age at arthroplasty [24,25]. This relationship was observed in the present study, where patients undergoing PKA were generally younger. While younger age may predispose such patients to activity-dependent failure modes such as aseptic loosening, the most common mode of failure for all PKA variants remains OA progression [157,181]. This represents a primary etiology that manifests independent of patient age, partially mitigating this consideration. While age stratified survivorship statistics would have been informative, the scarcity of registry data and lack of age grouping in cohort

**Table 4**
Comparative annual revision rates of cohort studies.

| | TKA | Medial UKA | Lateral UKA | PFA |
|---|---|---|---|---|
| Studies included | 43 | 35 | 13 | 24 |
| Annual revision rate | 0.46 | 1.04 | 1.13 | 1.74 |
| Confidence interval (95%) | 0.37–0.57 | 0.84–1.30 | 0.69–1.83 | 1.16–2.61 |
| *p*-Value | Reference | <0.001 | <0.001 | <0.001 |
| $I^2$ (%) | 95.20 | 89.07 | 65.97 | 79.52 |

*TKA*, total knee arthroplasty; *UKA*, unicompartmental knee arthroplasty; *PFA*, patellofemoral arthroplasty. Annual revision rate is expressed as the percentage of revisions per observed-component year. Significance testing was performed with meta-regression using TKA as the reference.

studies did not permit such analysis. Future meta-analyses incorporating age in the search strategy will be required to further refine this survivorship data.

## 5. Conclusions

Annual revision rates of MUKA (1.07%), LUKA (1.13%) and PFA (2.75%) occurred at a ratio of 2.18, 2.31 and 3.57, respectively, versus that of TKA (0.49%). Furthermore, no significant differences were detected between the annual revision rates of MUKA and LUKA. These estimates may be used to inform clinical decision-making, guide patient expectations and/or evaluate the cost-effectiveness of total versus partial knee replacement in the setting of unicompartmental knee OA.

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