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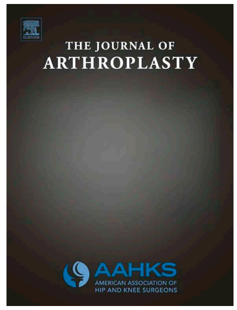
Hamilton, TW, Rizkalla, JM, Kontochristos, L et al. (5 more authors) (2017) The interaction of caseload and usage in determining outcomes of unicompartmental knee arthroplasty: A meta-analysis. Journal of Arthroplasty, 32 (10). 3228-3237.e2. ISSN 0883-5403

https://doi.org/10.1016/j.arth.2017.04.063

Accepted Manuscript



The interaction of caseload and usage in determining outcomes of unicompartmental knee arthroplasty: A meta-analysis

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PII: S0883-5403(17)30409-6

DOI: 10.1016/j.arth.2017.04.063

Reference: YARTH 55870

To appear in: *The Journal of Arthroplasty*

Received Date: 5 February 2017

Revised Date: 12 April 2017

Accepted Date: 29 April 2017

Please cite this article as: Hamilton T, Rizkalla J, Kontochristos L, Marks B, Mellon S, Dodd C, Pandit H, Murray D, The interaction of caseload and usage in determining outcomes of unicompartmental knee arthroplasty: A meta-analysis, *The Journal of Arthroplasty* (2017), doi: 10.1016/j.arth.2017.04.063.

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Abstract

Background: Outcomes following UKA are variable and influenced by surgical caseload (UKA/year) and usage (percentage of primary knee arthroplasty that are UKA), which relates to indications. This meta-analysis assesses the relative importance of these factors.

Methods: MEDLINE (Ovid), Embase (Ovid) and the Web of Science (ISI) were searched for consecutive series of minimally invasive cemented Phase 3 Oxford medial UKA. The primary outcome measure was revision-rate/100 observed component years (%pa). Series were divided into groups according to caseload and usage.

Results: 46studies, including 12,520 knees, were identified. The annual revision-rate varied from 0%pa to 4.35%pa, mean 1.21%pa (95%CI 0.97-1.47). In series with mean follow-up of ten-years or more the revision-rate was 0.63%pa (95%CI 0.46-0.83), which equates to a ten-year survival of 94% (95%CI 92%-95%). Aseptic loosening, lateral arthritis, bearing dislocation, and unexplained pain were the predominant failure mechanisms with revision for patello-femoral problems and polyethylene wear exceedingly rare (<0.1%).

Both increasing caseload (p=0.02) and usage (p<0.001) were associated with decreasing revision-rate. The lowest revision-rates were achieved with a caseload >24 UKA/year (0.88%pa, 95%CI 0.63-1.61) and usage >30% (0.69%pa, 95%CI 0.50-0.90). Usage was more important than caseload: with high-usage (≥20%) the revision-rate was low, whether the caseload was high (>12UKA/year) or low (≤12UKA/year), (0.94%pa (95%CI 0.69-1.23) and 0.85%pa (95%CI 0.65-1.08) respectively); whereas with low-usage (<20%) the revision-rate was high, whether the caseload was high or low (1.58%pa, 95%CI 0.57- 3.05 and 1.76%pa, 95%CI 1.21-2.41).

Conclusion: To achieve optimum results with mobile-bearing UKA surgeons, whether high or low-caseload, should adhere to the recommended indications such that ≥20%, or ideally >30%

of their knee replacements are UKA. If they do this then they can expect to achieve results similar to those of the long-term series, which all had high-usage (>20%) and an average ten-year survival of 94%.

Level of Evidence: Level 2

Keywords: Unicompartmental knee arthroplasty, implant survival, meta-analysis

Introduction

In appropriate patients UKA has significant benefits over TKA including faster recovery, better patient reported outcome measures (PROMS) and lower morbidity and mortality, however, it has been reported to be associated with a higher incidence of failure[1]. The causes of failure are multi-factorial but involve a complex interaction of patient, implant and surgeon factors as well as differing thresholds for revision compared to TKA[2].

Surgeon factors associated with outcome include technical skills associated with the procedure itself as well as non-technical skills associated with decision-making around patient selection. Technical skills have been hypothesised to improve as surgical volume increases and in TKA it has been demonstrated that high-volume surgeons have lower procedure times, transfusion rates and inpatient stays which culminate in better PROMS[3]. Similar findings have been reported in UKA, albeit more marked than TKA, with a fourfold difference in revision rates seen between the lowest and highest-volume surgeons using joint registry data suggesting that UKA may be more sensitive to technical errors [4].

Non-technical skills associated with decision-making around patient selection are related to surgical indications. In severe osteoarthritis which fails non-operative treatments surgeons can choose between UKA and TKA. This decision relates to an individual surgeon's indications, which is reflected by the relative proportions of a surgeon's primary knee practice that receive UKA relative to TKA. In UKA it has been demonstrated that, within certain limits, surgeons who use broad indications, as assessed by a high proportion of patients receiving UKA, have lower revision rates compared to surgeons who use narrow indications. The indications for mobile-bearing UKA are satisfied in about 50% of knees needing replacement. With mobile-bearing UKA acceptable revision rates tend to be achieved by surgeons who use UKA for 20% or more of their knee replacements and optimal results are achieved in those who use UKA for about 50% of their knee replacements [5].

It has been reported that optimum outcomes following UKA are achieved either when a surgeon operates on high-volume of cases (high-caseload) or has a practice where a high-proportion of primary knee arthroplasties are UKA (high-usage)[4, 5]. The relative importance of each of these factors on implant survival following UKA has not been explored. At present it is unclear whether good outcomes can be achieved when a surgeon has a high-caseload but uses narrow indications such that they have low-usage, or vice versa where a surgeon has a low-caseload but implants UKA in high proportion of cases (high-usage). This is relevant with regards to the provision of UKA as a surgeon cannot change the volume of their practice but can change percentage of knees which can be UKA.

The objective of this meta-analysis is review the results of the Phase 3 cemented Oxford UKA, to determine the importance of caseload and usage of UKA on implant survival and mechanism of failure and to assess the interplay between these two factors.

Materials and Methods

Search strategy and criteria

MEDLINE (Ovid), Embase (Ovid) and the Web of Science (ISI) were searched to identify studies reporting the outcomes of the cemented Phase 3 Oxford medial UKA (Zimmer Biomet, Warsaw, Indiana) implanted through a minimally invasive approach between 1998, the year the Phase 3 was introduced, and 17 March 2016. Appendix 1. In addition reference lists of included publications, published reviews, conference abstracts and experts in the field were contacted to identify additional reports.

Studies were excluded if they did not report the outcomes of a consecutive series of knees or did not present implant survival data. Registry studies were excluded due to the limitations in data reporting and obtaining volume and usage data for individual surgeons. There were no limits on language of publication, number of patients, duration of follow-up or indication.

Searches were performed in duplicate. All study authors were contacted to confirm the data extraction was correct and to determine caseload and usage of UKA. Figure 1.

Outcome measures assessed

For each study the number of UKA, number of revisions, reason for revision, and mean follow-up were recorded in duplicate. In addition the caseload (UKA/surgeon/year) and usage (percentage of the surgeons primary knee practice that are UKA) of UKA was recorded and/or requested from authors. Quality of included studies was assessed using the Methodological Index for Non-Randomised Studies (MINORS) score[6].

Caseload: UKA per surgeon per year

Surgical caseload was divided based according to clinically plausible cut-points a priori, based on the system employed by the New Zealand Joint Registry[7]. Surgeons performing ≤6UKA/year were considered very low-caseload, >6 and ≤12UKA/year low-caseload, >12 and ≤24UKA/year medium-caseload and >24UKA/year high-caseload.

Usage: UKA as a proportion of all primary knee arthroplasty

Very low-usage was defined as surgeons who performed <10%UKA, low-usage ≥10% but <20%UKA, medium-usage ≥20% but <30%UKA and high-usage ≥30%.

Combined caseload and usage

To explore the interaction between caseload and usage four groups were created based on: low-caseload (≤12UKA/year) and high-usage (≥20%UKA), high-caseload (>12UKA/year) and high-usage (≥20%UKA), low-caseload (≤12UKA/year) and low-usage group (<20%UKA), and high-caseload (>12UKA/year) and low-usage group (<20%UKA).

Statistical analysis

The primary outcome was the all cause revision rate per 100 observed component years, which is otherwise known as the annual revision rate (%pa). This was calculated first by multiplying the number of knees by their mean follow up to determine the number of observed component years and then dividing the number of revisions observed by the number of component years and multiplying this by 100. As revisions for bearing dislocation occur early after the primary operation, and as such may not have a constant annual revision rate the absolute revision rate was calculated. Confidence intervals (CI) were calculated using the Clopper-Pearson, exact, method[8]. As revision rates were expected to be low a Freeman-Tukey variance stabilising double arcsine transformation was used such that studies with zero rates would not be excluded[9]. Where a difference in the primary outcome was detected secondary outcomes were assessed: including the annual revision rate for lateral compartment disease progression, bearing dislocation, unexplained pain and aseptic loosening as these have been reported to be the predominant failure mechanisms of mobile-bearing UKA[4]. In addition the rates of other potential causes of revision, including revision for disease progression in the patello-femoral joint, polyethylene wear and tibial fracture were assessed.

As revision rates follow a binomial distribution a meta-analysis of proportions was performed with summary annual revision rates pooled using a random effects model to minimize the effect of between-study heterogeneity[10, 11]. Statistical heterogeneity across studies was assessed using the I^2 statistic[12].

Analysis was performed overall and based on those studies with long-term, mean 10-years or greater, outcomes with sub-group analysis based on caseload, usage and the interaction between caseload and usage as defined above. Analysis was conducted using Stata Version 13 (Stata Corp, Texas, USA) with a $p<0.05$ considered statistically significant.

Results

Searches identified a total of 3585 papers with an additional five-studies identified. Figure 1. After screening, the full-texts of 83 studies were retrieved and assessed with 37 excluded (Appendix 2) leaving 46 (12,520 knees 67,128 component years) meeting inclusion criteria. Table 1. The mean MINORS score of included studies was 12 (range 10-14).

After contacting authors, data on the caseload was available for 37 studies (80%) and on usage for 34 studies (74%). Table 2. The smallest study, Palacios *et al.*, had 24 observed component years and reported no failures and was found to skew the revision estimate towards zero[13]. Therefore, as generally recommended, this study was excluded from the quantitative analysis[13]. The analysis was repeated including this study and this did not change the interpretation of the results.

The all cause revision rate was 1.21%pa (95%CI 0.97-1.47). Revision indications are outlined in Table 3. The revision rate for aseptic loosening was 0.19% pa (95%CI 0.09 to 0.32), for lateral compartment disease progression was 0.10% pa (95%CI 0.04 to 0.19), bearing dislocation 0.10% pa (95%CI 0.05 to 0.17) and unexplained pain 0.05% pa (95%CI 0.01 to 0.11). Table 3. Out of the 12,520 knees there were 121 (0.97%) dislocations, 20 (0.16%) tibial plateau fracture, 7 (0.06%) revisions for patella-femoral disease and 1 (0.01%) revision for polyethylene wear secondary to anterior impingement. In series with long-term outcomes, mean follow-up 10-years or greater, the all cause revision rate was 0.63%pa (95%CI 0.46-0.83). Table 3 & 4.

Caseload: UKA per surgeon per year

No difference in mean age (p=0.69), gender (p=0.71) or BMI (p=0.38) was seen between groups based on caseload.

The revision rate decreased as the caseload increased (p=0.02). Figure 2. The revision rate where surgeons performed: ≤6 UKA/year was 1.87%pa (95%CI 1.14-2.76), >6 but ≤12 UKA/year was 1.25%pa (95%CI 0.77-1.83), >12 but under ≤24 UKA/year was 1.37%pa (95%CI 0.93-1.89) and >24 UKA/year was 0.88%pa (95%CI 0.63-1.61).

The revision rate for lateral compartment disease progression (p=0.005), unexplained pain (p=0.02) and aseptic loosening (p=0.003) decreased as caseload increased. No difference in annual revision rate (p=0.58) or absolute revision rate (p=0.17) for bearing dislocation was detected. Table 3.

Usage: UKA as a proportion of all primary knee arthroplasty

As usage of UKA increased the mean age increased (p=0.04). The mean age of patients in surgeons who performed UKA in <10% of cases was 63.4 years (SD4.2) increasing to 69.4 years (SD4.3) in surgeons who implanted UKA in at ≥30% of cases. No difference in gender (p=0.27) or BMI (p=0.32) was seen.

The revision rate decreased as usage of UKA increased (p<0.001). Figure 3. The revision rate in series where surgeons performed: <10% UKA was 1.89%pa (95%CI 1.15-2.80), ≥10% but <20% UKA was 1.48%pa (95%CI 0.91-2.18), ≥20% but <30% UKA was 1.25%pa (95%CI 1.07-1.43) and ≥30% was 0.69%pa (95%CI 0.50-0.90).

The revision rate for unexplained pain (p=0.02) and aseptic loosening (p=0.001) decreased as the usage of UKA increased. No difference in annual revision rate (p=0.94) or absolute revision rate (p=0.33) for bearing dislocation, or annual revision rate for lateral compartment disease progression (p=0.10) was seen. Table 3.

Combined caseload and usage

No difference in mean age (p=0.84), gender (p=0.73) or BMI (p=0.19) was seen based on the combined caseload and usage of UKA.

Significant differences in revision rate were seen between groups (p=0.004) with lower revision rates seen where there was higher UKA usage. The revision rate was 0.85%pa (95%CI 0.65-1.08) in the low-caseload (≤12 UKA/year) and high-usage group (≥20% UKA) and 0.94%pa (95%CI 0.69-1.23) in the high-caseload (>12 UKA/year) and high-usage (≥20% UKA) group compared to 1.76%pa (95%CI 1.21-2.41) in the low-caseload (≤12 UKA/year) and low-usage group (<20% UKA) and 1.58%pa (95%CI 0.57-3.05) in the high-caseload (>12 UKA/year) and low-usage (<20% UKA) group. (With the Palacios *et al.* study included the revision rate in the low-caseload, high-usage group was 0.32%pa (95%CI 0.16-0.52)). Figure 4.

Significant differences in the revision rate for lateral compartment disease progression (p=0.002), persistent pain (p=0.01) and aseptic loosening (p=0.001) were observed with the lowest revision rates seen in the high-caseload high usage series. No difference in annual revision rate (p=0.71) or absolute risk of revision (p=0.71) for bearing dislocation was detected. Table 3.

Discussion

In published series of the cemented Phase 3 Oxford medial UKA (46studies, 12,520knees, 67,128component years) the all cause revision rate was 1.21%pa (95%CI 0.97-1.47) falling to 0.63%pa (95%CI 0.46-0.83) in series with a mean follow-up of 10-years or greater. Table 3. Aseptic loosening, progression of disease in the lateral compartment, bearing dislocation, and unexplained pain represented the predominant failure mechanisms with revisions for patella-femoral joint disease (7cases) and polyethylene wear (1case) being exceedingly rare (<0.1%).

Revision rates decreased with both increasing surgeon caseload (UKA/surgeon/year) and usage (percentage of primary knee arthroplasty that are UKA). It is well recognised, and expected, that revision rate should decrease with increasing caseload[4]. It is however counterintuitive that it should increase with usage. Kozinn & Scott (1989) described the ideal indications for a UKA, and subsequent studies suggested that these were satisfied in about 5% of knee replacements [14-16]. Kozinn and Scott also suggested that with broader indications, and thus increased usage, the revision rate would increase. This meta-analysis is the first review of clinical studies that has shown that this is not the case, supporting analysis of Registry data, and concluding that the revision rate decreases with increased usage, at least for mobile-bearing UKA[5].

Usage was found to be more important than caseload: Usage was independent of caseload, with high-usage surgeons achieving equally good results regardless of their overall caseload, whereas caseload was not independent of usage. In low-usage surgeons the annual revision rate was almost double that of high-usage surgeons regardless of whether surgeons implanted a high number of UKA (high-caseload) or not (low-caseload). The results of this study therefore suggest that to achieve optimum outcomes mobile-bearing UKA should be performed in a high proportion of a surgeon's practice and suggests that surgeons who perform a low number of knee arthroplasties can still achieve good results provided that UKA is performed in an adequate proportion. There were no studies available for high usage, very low-caseload surgeons (<6UKA/year), and as such we cannot recommend that surgeons do such small numbers, even if their usage is acceptable.

As low-usage surgeons have a high revision rate, regardless of whether they have a low or high-caseload, the reasons for this are likely to be related to their indications for UKA, or possibly for revision of UKA, rather than their surgical technique. The primary indication for mobile-bearing UKA is antero-medial OA. This requires (a) medial bone-on-bone arthritis (b) functionally normal ACL (c) functionally normal MCL (d) full thickness lateral cartilage and (e) patellofemoral joint without lateral grooving and bone loss[17]. It has been demonstrated that around 50% of cases undergoing knee arthroplasty meet these criteria and that suitability for UKA can be identified pre-operatively using a structured radiographic assessment in combination with a radiographic Decision Aid[18]. It is striking that the lowest revision rate (0.69%pa) was achieved by those doing >30% of their knee replacements as UKA, who were presumably adhering closely to the recommended indications.

Surgeons performing UKA in a low-proportion of cases and obtaining poor results are probably using inappropriate indications. Surgeons may be concerned that UKA will fail because of progression of disease in the retained compartments. Therefore they may only implant UKA if the retained compartments are pristine, which usually only occurs if there is early arthritis with partial thickness cartilage loss (PTCL) in the medial compartment. It is well known that patients with PTCL do not do well with TKA, so a mobile-bearing UKA may seem to be an ideal solution, as these patients tend to be young and active. However patients with PTCL also do badly with UKA and have worse outcomes compared to those with bone-on-bone anteromedial osteoarthritis[19, 20]. Whilst we can only speculate as to the reasons for failure, this study found that low-usage UKA surgeons operated on younger patients, and had revision rates for persistent pain that were ten-fold higher than high-usage surgeons, with both these features being associated with operating on knees with PTCL. Recent work has highlighted that around a quarter of young patients (<60 years) undergoing arthroplasty are not suitable for UKA due to PTCL and it may be that low usage surgeons are performing UKA in these patients and achieving poor results as a consequence[21]. Further work is required to confirm this finding, as well as to clarify the results of registry studies which have reported higher failure rates of UKA in young patients, a finding not observed in cases series performed for bone-on-bone arthritis [22-24].

A final consideration is that, the higher revision rate in low-usage surgeons may relate to their indications for revision. In this study low-usage surgeons had a higher revision rate due to aseptic loosening compared to high-usage surgeons. Aseptic loosening is typically identified radiographically by the presence of radiolucent lines around the prosthesis[25]. Following mobile-bearing UKA two types of tibial radiolucency are recognized: Physiological radiolucencies are common, occurring in two thirds of cases, and are non-progressive, narrow (<2mm) with well-defined sclerotic margins. They are not indicative or predictive of loosening nor are they a source of pain[26-28]. In contrast pathological radiolucencies are rare, progressive and poorly-defined and are suggestive of loosening or infection. It is likely that surgeons who have not learnt the correct indications for mobile-bearing UKA, and are therefore low-usage surgeons, have also not understood the relevance of these radiolucencies, and may be doing unnecessary revisions for physiological radiolucencies[29].

Whilst this study found a relationship between caseload and implant survival it was only the high-usage surgeons, >24 UKA/year, which appeared to have a lower failure rate. Figure 2. This result is different from previous studies which have reported a progressive decrease in failure rate with increasing caseload with revision rates in high-caseload series typically half to a quarter of that seen in low-caseload series[4, 30, 31]. One reason this relationship may not have been seen in this study is that in almost a quarter of the high-caseload studies included in this analysis were low-usage (4 of 17studies), which we found to be associated with higher failure rate[29, 32-34] . In cross-sectional studies, because of the relationship between caseload and usage, we would expect the number of high-volume and low-usage UKA surgeons to be lower than seen in this series[4]. As such usage may be a confounding variable that has not been accounted for in previous reports.

In series reporting the long-term outcomes (mean follow-up of 10-years or greater) of mobile-bearing UKA the survival rate was 94% (95%CI 92–95). Table 3. This result is better than the 10-year survival rate (88%, 95%CI 85-90) extrapolated from the annual revision rate for all series, which have, on average a shorter follow-up. One reason for this is that the annual revision rate tends to overestimate the long-term failure rate, particularly in studies with a high incidence of early failures and a short duration of follow-up. This is relevant to this study: firstly because with mobile-bearing UKA bearing dislocation tends to occur early, and secondly because many of the included studies represent the learning curve of the surgeons who may have more revisions during this period. However, the main reason why the revision rate of the 10-year series is lower than all series combined is that all the ten-year series were from high-usage surgeons, whereas the other series came from a mixture of low and high-usage surgeons with low-usage surgeons tending to get worse results. The main conclusion from this study is therefore that if surgeons want to use the mobile-bearing UKA they should use it for a high-proportion of their knee replacements (≥20%). If they do this they should expect to achieve a similarly good survival as seen in studies with long-term outcomes (94% ten-year survival).

There are limitations of this study: surgeons may over or understate their UKA caseload and usage, presenting a risk of recall bias. Due to limited information provided in published series it was not possible to evaluate functional outcomes which are critical in evaluating the optimum treatment. The study is based on published case series of UKA, which are open to publication bias. As the results of arthroplasty are expected to be good it may be easier to get poor results published early and these need only be based on small numbers of patients. In contrast it is difficult to get good results published, as these require large numbers of patients with long follow-up. Therefore a higher proportion of poor results may be published than good.

Conclusion

To achieve optimum results with mobile-bearing UKA surgeons should use it for at least 20%, and ideally 50% of their knee replacements. To do this they should adhere to the recommended indications. This effect appears to be independent of the caseload of UKA performed meaning that optimum results can still achieved by relatively low-volume surgeons (>6 and <12/year). Surgeons with optimal usage should be able to achieve a 10-year survival of about 94%.

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Table 1: Demographic Information of included studies

Study	Country	Age	Age range	% male	BMI	BMI range	MINORS Score
Akan 2013[35]	Turkey	64	42 - 84	17	29.8	19 – 42	11
Amin 2006[36]	UK	68	40 - 91	50	29.2	21 – 43	13
Aslan 2007[37]	Turkey	57	47 - 73	11	NS		11
Bergeson 2013[38]	USA	63	29 - 91	44	32.2	17 – 58	11
Bhattacharya 2012[32]	UK	69	50 - 83	50	NS		12
Biau 2013[39]	Canada	60	55 - 65	33	32.0	29 – 34	11
Bottomley 2016[40]	UK	67		49	NS		12
Bozkurt 2013[41]	Turkey	57		NS	NS		11
Burnett 2014[42]	Canada	69	40 - 88	44	29.7	18 – 49	14
Choy 2011[43]	South Korea	65	44 - 82	10	NS		12
Cinar 2010[44]	Turkey	58	44 - 76	8	NS		11
Clarius 2010[45]	Germany	63	45 - 78	49	29.0	20 – 42	13
Clark 2010[46]	Australia	64	45 - 81	NS	NS		11
Clement 2012[47]	UK	70		43	NS		12
Cool 2006[48]	Belgium	66	45 - 90	29	27.5		12
Davidson 2013[49]	UK	65	41 - 87	51	NS		10
Dervin 2011[33]	Canada	65	38 - 89	43	30.1	19 – 53	11
Edmondson 2011[50]	UK	67	57 - 86	NS	NS		11
Emerson 2016[51]	USA	67	38 - 89	55	29.9	17 – 62	13
Falcao 2014[52]	Portugal	64	49 - 78	15	NS		11
Faour-Martin 2013[53]	Spain	59		29	27.1		12
Heller 2009[54]	Israel	63	45 - 80	32	NS		11
Ingale 2013[55]	UK	67	42 - 92	NS	29.3		12
Ji 2014[56]	South Korea	64	50 - 76	15	NS		11
Keys 2013[57]	UK	69	40 - 87	NS	NS		13
Kim KT 2015[58]	South Korea	62	45 - 75	NS	NS		12
Kim SJ 2012[59]	South Korea	67	49 - 79	19	NS		14
Kort 2007[60, 61]	The Netherlands	66	43 - 93	34	30.7		11
Kuipers 2010[62]	The Netherlands	63	39 - 85	32	NS		11
Lim 2012[63]	South Korea	69	48 - 82	NS	NS		13
Lisowski 2011[64]	The Netherlands	73	43 - 91	NS	28.0	19 – 52	12
Luscombe 2007[65]	UK	63	41 - 79	NS	28.4		11
Mallen 2014[66]	Mexico	71	57 - 81	16	28.1	19 – 36	11
Matharu 2012[67]	UK	63	35 - 87	NS	NS		11
Munk 2011[34]	Denmark	66		51	NS		11
Nerhus 2012[68]	Norway	65	51 - 80	41	NS		11
Palacios 2007[69]	Mexico	NS	55 - 74	32	NS		10
Pandit 2015[28]	UK	66	32 - 88	48	NS		13
Parmaksızoglu 2012[70]	Turkey	67	56 - 75	26	NS		10
Petersen 2013[71]	Germany	71	59 - 79	NS	NS		11
Schroer 2013[29]	USA	57	40 - 76	58	NS		12
Smith 2012[72]	UK	67		NS	NS		11
Song 2009[73]	South Korea	66	57 - 82	7	NS		11
Wagner-Kristensen 2013[74]	Denmark	64	30 - 94	NS	NS		12
Whittaker 2010[75]	Canada	63	49 - 87	NS	30.7	19.3 - 43.1	10
Yoshida 2013[76]	Japan	77	47 - 94	18	NS		13

NS: Not stated.

Table 2: Details of included studies

Study	Number of knees	Number of patients	Mean follow-up (years)	Follow-up range (years)	Number of revisions	Caseload (UKA/surgeon/year)	Usage (% UKA)
Akan 2013[35]	141	120	3.5	2.0 - 4.3	10	21	NS
Amin 2006[36]	54	54	4.9	2.0 - 5.9	6	NS	NS
Aslan 2007[37]	27	27	2.3	2.0 - 3.0	2	NS	NS
Bergeson 2013[38]	839	688	3.7	0.1 - 6.5	40	111	22
Bhattacharya 2012[32]	49	44	5.6	2.0 - 9.9	1	15	5
Biau 2013[39]	37	33	5.3	4.9 - 6.3	1	12	8
Bottomley 2016[40]	1084	947	5.2		46	8	50
Bozkurt 2013[41]	53	NS	1.2	0.5 - 3.3	1	NS	15
Burnett 2014[42]	467	387	6.1	0.7 - 11.6	42	6	13
Choy 2011[43]	188	166	6.7	4.7 - 8.6	17	48	34
Cinar 2010[44]	41	40	1.6	0.8 - 3.5	1	NS	8
Clarius 2010[45]	61	59	5.0	4.0 - 7.0	2	3	13
Clark 2010[46]	398	398	3.6	1.0 - 8.5	15	11	20
Clement 2012[47]	49	49	7.2		4	12	13
Cool 2006[48]	50	49	3.7	2.6 - 5.0	3	NS	NS
Davidson 2013[49]	699	699	4.2		39	54	27
Dervin 2011[33]	545	545	3.8	2.3 - 7.4	32	18	17
Edmondson 2011[50]	48	48	4.5	3.0 - 6.0	4	6	6
Emerson 2016[51]	213	173	10.0	4.0 – 11.0	20	85	40
Falcao 2014[52]	29	27	3.9	0.8 - 6.9	2	NS	NS
Faour-Martin 2013[53]	511	402	10.4		29	85	NS
Heller 2009[54]	59	59	2.7		7	7	5
Ingale 2013[55]	470	NS	3.9		29	5	9
Ji 2014[56]	246	245	2.8	1.0 - 8.0	20	16	NS
Keys 2013[57]	107	NS	11.5		6	24	31
Kim KT 2015[58]	166	128	10.0		16	83	23
Kim SJ 2012[59]	124	104	6.7	4.2 - 9.1	3	40	NS
Kort 2007[60, 61]	200	175	4.0	2.0 - 7.0	19	8	4
Kuipers 2010[62]	437	437	2.6	0.1 - 7.9	45	5	10
Lim 2012[63]	400	320	5.2	1.0 - 10.0	14	44	30
Lisowski 2011[64]	244	216	4.2	1.0 - 10.4	9	27	40
Luscombe 2007[65]	78	68	2.0		4	23	22
Mallen 2014[66]	30	25	6.1	1.1 - 11.5	3	3	
Matharu 2012[67]	459	392	4.4	0.5 - 11.2	23	8	18
Munk 2011[34]	268	268	1.0		3	19	15
Nerhus 2012[68]	99	96	2.0		6		
Palacios 2007[69]	24	22	1.0	0.7 - 3.0	0	6	33
Pandit 2015[28]	1000	818	10.3	5.3 - 16.6	52	50	70
Parmaksızoglu 2012[70]	38	38	2.0	1.5 - 2.7	0	NS	NS
Petersen 2013[71]	50	NS	5.0		3		NS
Schroer 2013[29]	83	77	3.6	0.3 - 7.1	13	28	7
Smith 2012[72]	230	NS	7.3		21	19	23
Song 2009[73]	100	94	9.0		9	43	23
Wagner-Kristensen 2013[74]	695	579	4.6	0.0 - 10.7	51	24	22
Whittaker 2010 [75]	79	62	3.6	1.0 - 11.3	7	5	7
Yoshida 2013[76]	1251	990	5.2	1.0 – 10.5	25	114	70

Table 3: Indications for revision

	All Cause	**Aseptic Loosening**	**Lateral Progression**	**Bearing Dislocation**	**Unexplained Pain**
All series	1.21%pa (95%CI 0.97 to 1.47)	0.19%pa (95%CI 0.09 to 0.32)	0.10%pa (95%CI 0.04 to 0.19)	0.10%pa (95%CI 0.05 to 0.17)	0.05%pa (95%CI 0.01 to 0.11)
Caseload					
≤6 UKA pa	1.87%pa (95%CI 1.14 to 2.76)	0.36%pa (95%CI 0.15 to 0.64)	0.59%pa (95%CI 0.35 to 0.87)	0.08%pa (95%CI 0.01 to 0.19)	0.19%pa (95%CI 0 to 0.60)
>24 UKA pa	0.88%pa (95%CI 0.63 to 1.61)	0.07%pa (95%CI 0.01 to 0.19)	0.15%pa (95%CI 0.04 to 0.32)	0.21%pa (95%CI 0.10 to 0.35)	0.03%pa (95%CI 0 to 0.09)
p-value	**0.02**	**0.03**	**0.005**	0.58	**0.02**
Usage					
<10%	1.89%pa (95%CI 1.15 to 2.80)	0.65%pa (95%CI 0.17 to 1.36)	0.19%pa (95%CI 0.05 to 0.39)	0.04%pa (95%CI 0 to 0.18)	0.22%pa (95%CI 0.02 to 0.57)
≥30%	0.69%pa (95%CI 0.50 to 0.90)	0.09%pa (95%CI 0.01 to 0.22)	0.12%pa (95%CI 0.03 to 0.26)	0.17%pa (95%CI 0.07 to 0.15)	0.02%pa (95%CI 0.01 to 0.12)
p-value	**<0.001**	**0.001**	0.10	0.94	**0.02**
Combined					
Low caseload, Low usage	1.76%pa (95%CI 1.21 to 2.41)	0.56%pa (95%CI 0.34 to 0.82)	0.23%pa (95%CI 0.08 to 0.44)	0.08%pa (95%CI 0.02 to 0.17)	0.28%pa (95%CI 0.07 to 0.58)
High caseload, Low usage	1.58%pa (95%CI 0.57 to 3.05)	0.62%pa (95%CI 0 to 2.17)	0.58%pa (95%CI 0.31 to 0.91)	0.06%pa (95%CI 0 to 0.23)	0.09%pa (95%CI 0 to 0.27)
Low caseload, High usage	0.85%pa (95%CI 0.65 to 1.08)	0.23%pa (95%CI 0.13 to 0.36)	0.24 (95%CI 0.14 to 0.38)	0.12%pa (95%CI 0.05 to 0.22)	0.06%pa (95%CI 0.01 to 0.13)
High caseload, High usage	0.94%pa (95%CI 0.69 to 1.23)	0.16%pa (95%CI 0.05 to 0.31)	0.12%pa (95%CI 0.04 to 0.25)	0.18%pa (95%CI 0.08 to 0.30)	0.04%pa (95%CI 0 to 0.11)
p-value	**0.004**	**0.001**	**0.002**	0.71	**0.01**

Table 4: Studies with mean follow-up of 10 years or greater

Study	Number of knees	Annual revision rate (%pa)	Annual revision rate 95% CI (%pa)	10y survival (%)	10y survival (%) 95% CI	Caseload (UKA/surgeon/year)	Usage (% UKA)
Emerson 2016[51]	213	0.94	0.57 – 1.45	90.6	85.5 – 94.3	85	40
Faour-Martin 2013[53]	511	0.55	0.37 – 0.78	94.5	92.2 – 96.3	85	NS
Keys 2013[57]	107	0.49	0.18 – 1.06	95.1	89.4 – 98.2	24	31
Kim KT 2015[58]	166	0.96	0.55 – 1.56	90.4	84.4 – 94.5	83	23
Pandit 2015[28]	1000	0.50	0.38 – 0.66	95.0	93.4 – 96.2	50	70
OVERALL		0.63	0.46 – 0.83	93.7	91.7 – 95.4		

Appendix 1

1. Arthroplasty, Replacement, Knee/
2. Partial.ab
3. unicompartmental.ab
4. unicondylar.ab
5. uni.ab
6. UKA.ab
7. UKR.ab
8. UCA.ab
9. UCR.ab
10. PKA.ab
11. PKR.ab
12. PCA.ab
13. Oxford.ab
14. meniscal.ab
15. mobile.ab
16. OR/ 2-15
17. 1 AND 16
18. 17 (limited to humans)

Database searched	**Date searched**	**Number of results**
MEDLINE (OVID) & in Process 1946 to March 16, 2016	17/03/2016	1554
EMBASE (OVID) 1996 to Week 11 2016	17/03/2016	975
ISI Web of Science (SCI, SSCI, CPCI-S & CPCI-SSH) searched to 20/01/15	17/03/2016	1056
Total		**3585**

626 ## Appendix 2: Excluded studies

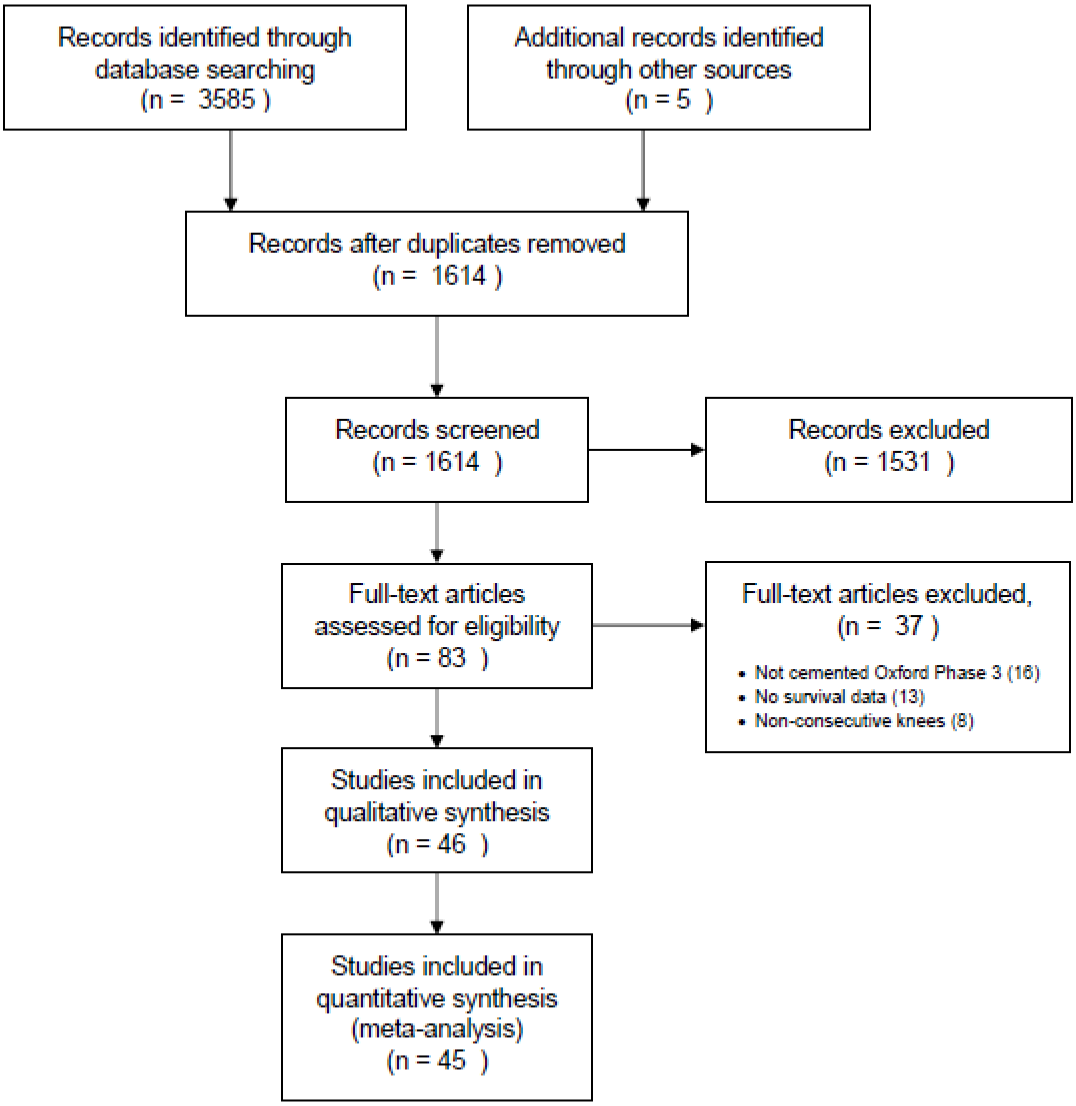
Study	Country	Reason excluded
Aldinger 2004[77]	Germany	No survival data
Catani 2012[78]	Italy	No survival data
Chatellard 2013[79]	France	Not cemented Oxford Phase 3
Daniilidis 2009[80]	Germany	No survival data
Emerson 2002[81]	USA	Not cemented Oxford Phase 3
Emerson 2008[82]	USA	Not cemented Oxford Phase 3
Gleeson 2004[83]	UK	Non-consecutive patients
Hooper 2015[84]	New Zealand	Not cemented Oxford Phase 3
Jahromi 2004[85]	Australia	No survival data
Kaczmarczyk 2003[86]	Poland	No survival data
Kendrick 2015[87]	UK	No survival data
Kubat 2011[88]	Czech Republic	No survival data
Langdown 2005[89]	UK	Non-consecutive patients
Li 2006[90]	Australia	Non-consecutive patients
Liddle 2013[91]	UK	Not cemented Oxford Phase 3
Ma 2013[92]	China	No survival data
Mascitti 2005 [93]	Italy	No survival data
Masri 2009[94]	Canada	Non-consecutive patients
Mercier 2010[95]	France	Not cemented Oxford Phase 3
Mullaji 2011[96]	India	No survival data
Muller 2004[97]	Germany	Not cemented Oxford Phase 3
Nassiri 2010[98]	Ireland	Non-consecutive patients
Pandit 2013[99]	UK	Not cemented Oxford Phase 3
Pandit 2015[100]	UK	Not cemented Oxford Phase 3
Parratte 2012[101]	France	Not cemented Oxford Phase 3
Pietschmann 2014[102]	Germany	No survival data
Rajasekhar 2004 [103]	UK	Not cemented Oxford Phase 3
Shakespeare 2012[104]	UK	No survival data
Skowronski 2005[105]	Poland	Not cemented Oxford Phase 3
Streit 2015[106]	Germany	Non-consecutive patients
Sun 2012[107]	China	Non-consecutive patients
Tang 2012[108]	China	No survival data
Tuncay 2015[109]	Turkey	Non-consecutive patients
Verdonk 2005[110]	Belgium	Not cemented Oxford Phase 3
Volpin 2006	Israel	No survival data
Vorlat 2006[111]	Belgium	Not cemented Oxford Phase 3
White 2012[112]	UK	Not cemented Oxford Phase 3
Zermatten 2012[113]	Switzerland	Not cemented Oxford Phase 3

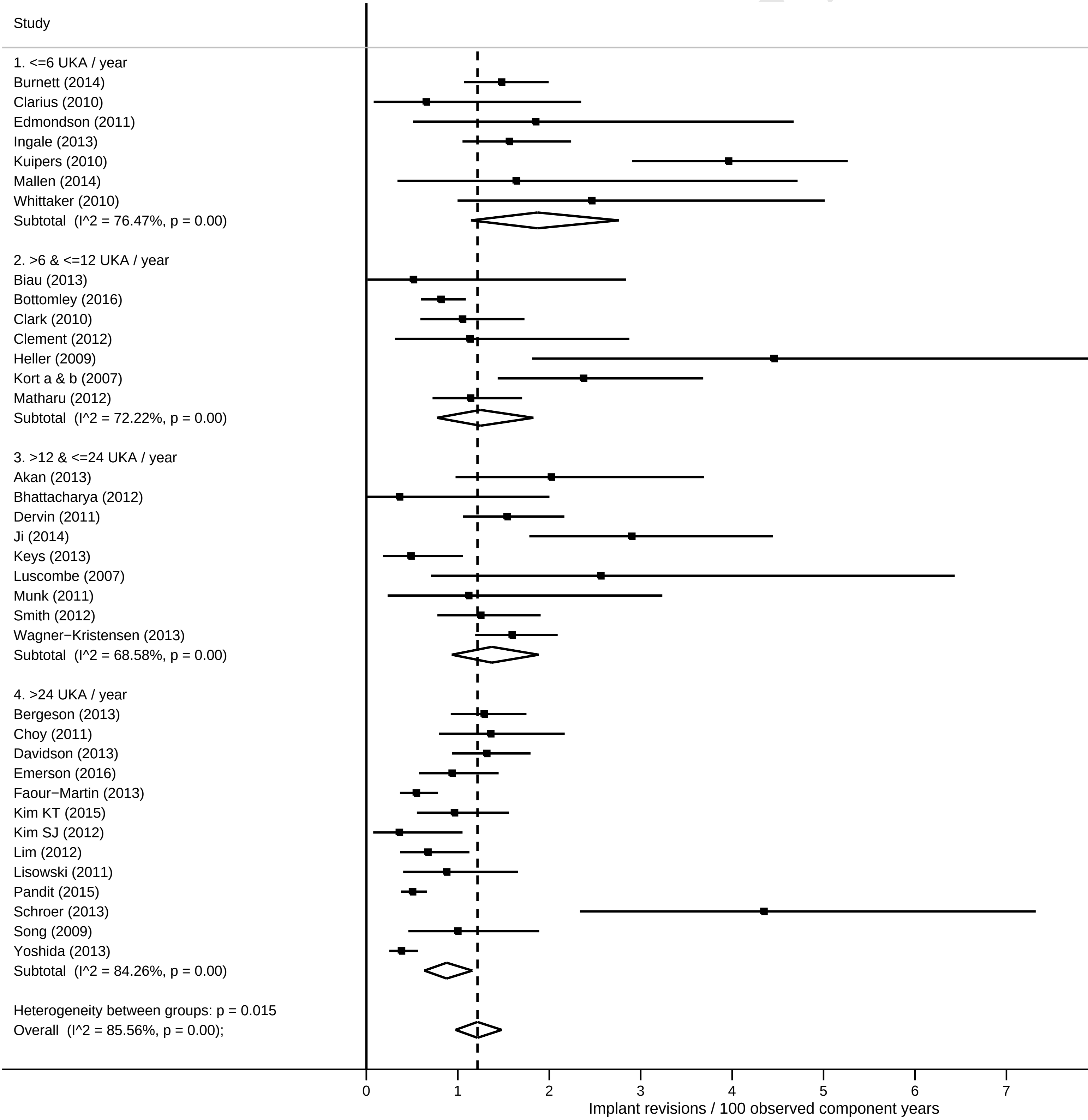
627

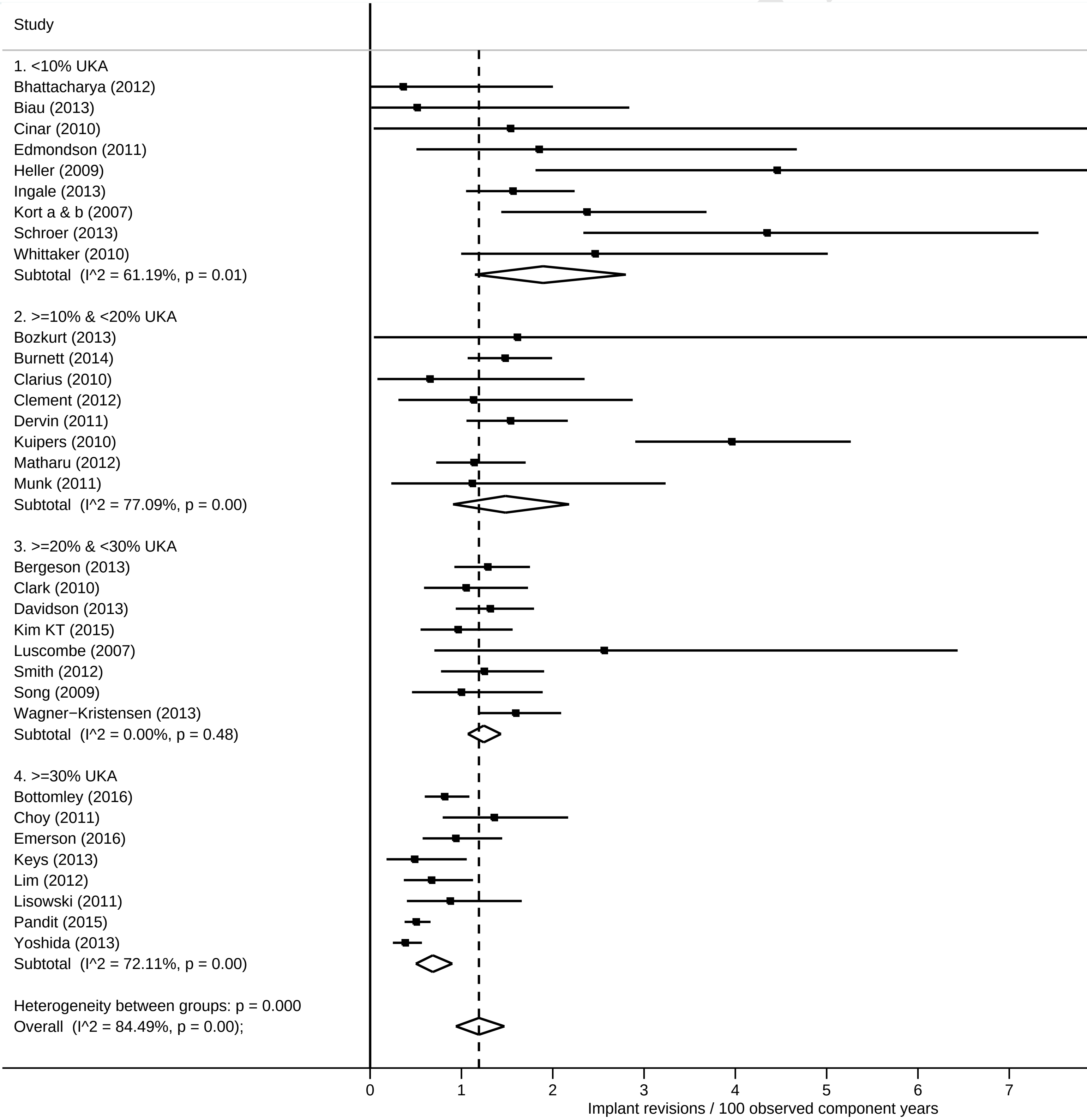
Acknowledgements:

The authors would like to thank J. Brown and J. Ferris for their assistance with this study. TWH has been supported by the NIHR Biomedical Research Centre, based at Oxford University Hospitals Trust, Oxford. The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health. Financial support has been received from Zimmer Biomet.

ACCEPTED MANUSCRIPT


Records identified through database searching (n = 3585)
Additional records identified through other sources (n = 5)
Records after duplicates removed (n = 1614)
Records screened (n = 1614)
Records excluded (n = 1531)
Full-text articles assessed for eligibility (n = 83)
Full-text articles excluded, (n = 37)
Not cemented Oxford Phase 3 (16)
No survival data (13)
Non-consecutive knees (8)
Studies included in qualitative synthesis (n = 46)
Studies included in quantitative synthesis (meta-analysis) (n = 45)


Study
1. <=6 UKA / year
Burnett (2014)
Clarius (2010)
Edmondson (2011)
Ingale (2013)
Kuipers (2010)
Mallen (2014)
Whittaker (2010)
Subtotal (I^2 = 76.47%, p = 0.00)
2. >6 & <=12 UKA / year
Biau (2013)
Bottomley (2016)
Clark (2010)
Clement (2012)
Heller (2009)
Kort a & b (2007)
Matharu (2012)
Subtotal (I^2 = 72.22%, p = 0.00)
3. >12 & <=24 UKA / year
Akan (2013)
Bhattacharya (2012)
Dervin (2011)
Ji (2014)
Keys (2013)
Luscombe (2007)
Munk (2011)
Smith (2012)
Wagner−Kristensen (2013)
Subtotal (I^2 = 68.58%, p = 0.00)
4. >24 UKA / year
Bergeson (2013)
Choy (2011)
Davidson (2013)
Emerson (2016)
Faour−Martin (2013)
Kim KT (2015)
Kim SJ (2012)
Lim (2012)
Lisowski (2011)
Pandit (2015)
Schroer (2013)
Song (2009)
Yoshida (2013)
Subtotal (I^2 = 84.26%, p = 0.00)
Heterogeneity between groups: p = 0.015
Overall (I^2 = 85.56%, p = 0.00);
0
1
2
3
4
5
6
7
Implant revisions / 100 observed component years


Study
1. <10% UKA
Bhattacharya (2012)
Biau (2013)
Cinar (2010)
Edmondson (2011)
Heller (2009)
Ingale (2013)
Kort a & b (2007)
Schroer (2013)
Whittaker (2010)
Subtotal (I^2 = 61.19%, p = 0.01)
2. >=10% & <20% UKA
Bozkurt (2013)
Burnett (2014)
Clarius (2010)
Clement (2012)
Dervin (2011)
Kuipers (2010)
Matharu (2012)
Munk (2011)
Subtotal (I^2 = 77.09%, p = 0.00)
3. >=20% & <30% UKA
Bergeson (2013)
Clark (2010)
Davidson (2013)
Kim KT (2015)
Luscombe (2007)
Smith (2012)
Song (2009)
Wagner−Kristensen (2013)
Subtotal (I^2 = 0.00%, p = 0.48)
4. >=30% UKA
Bottomley (2016)
Choy (2011)
Emerson (2016)
Keys (2013)
Lim (2012)
Lisowski (2011)
Pandit (2015)
Yoshida (2013)
Subtotal (I^2 = 72.11%, p = 0.00)
Heterogeneity between groups: p = 0.000
Overall (I^2 = 84.49%, p = 0.00);
0
1
2
3
4
5
6
7
Implant revisions / 100 observed component years

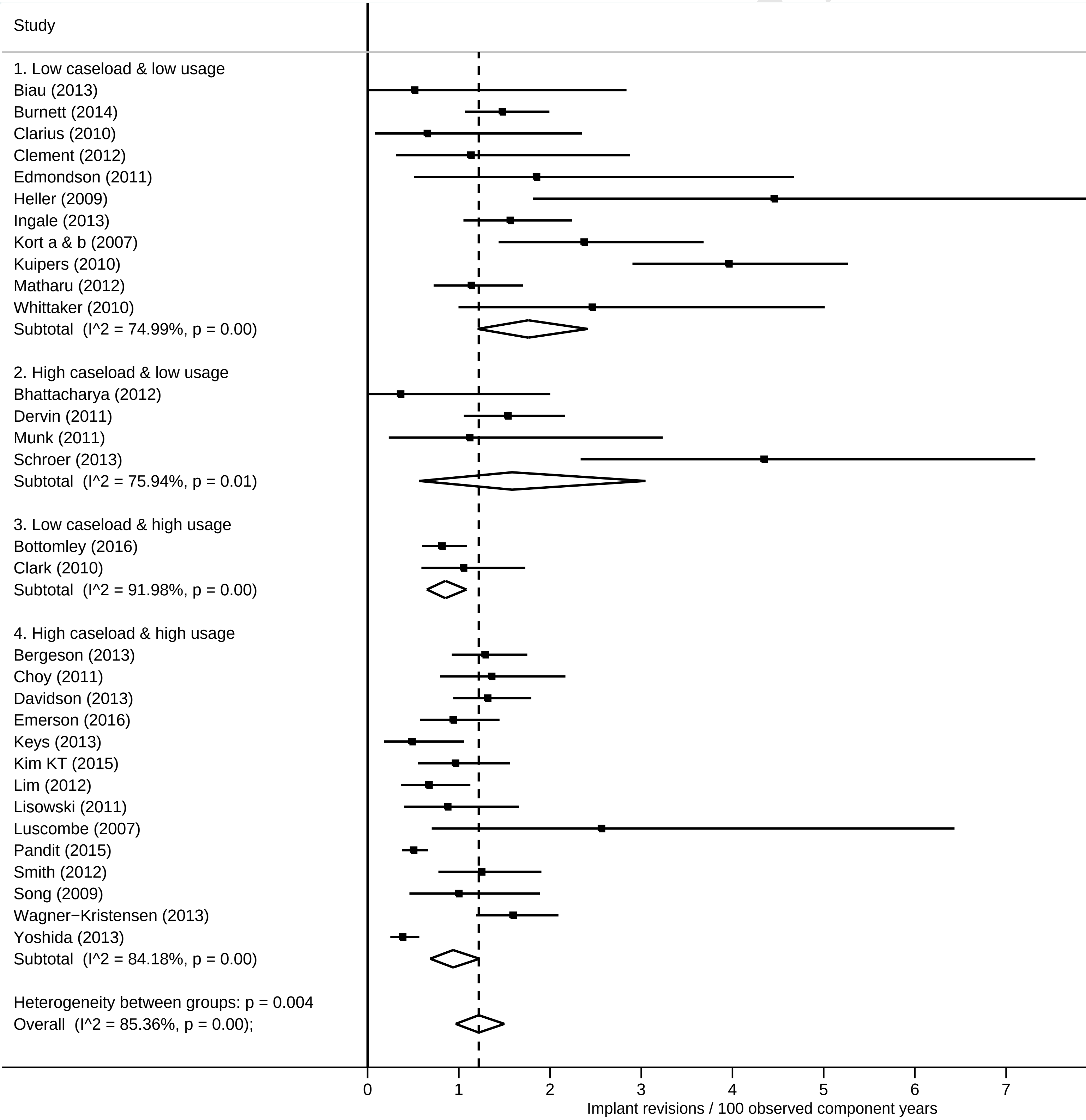

Study
1. Low caseload & low usage
Biau (2013)
Burnett (2014)
Clarius (2010)
Clement (2012)
Edmondson (2011)
Heller (2009)
Ingale (2013)
Kort a & b (2007)
Kuipers (2010)
Matharu (2012)
Whittaker (2010)
Subtotal (I^2 = 74.99%, p = 0.00)
2. High caseload & low usage
Bhattacharya (2012)
Dervin (2011)
Munk (2011)
Schroer (2013)
Subtotal (I^2 = 75.94%, p = 0.01)
3. Low caseload & high usage
Bottomley (2016)
Clark (2010)
Subtotal (I^2 = 91.98%, p = 0.00)
4. High caseload & high usage
Bergeson (2013)
Choy (2011)
Davidson (2013)
Emerson (2016)
Keys (2013)
Kim KT (2015)
Lim (2012)
Lisowski (2011)
Luscombe (2007)
Pandit (2015)
Smith (2012)
Song (2009)
Wagner−Kristensen (2013)
Yoshida (2013)
Subtotal (I^2 = 84.18%, p = 0.00)
Heterogeneity between groups: p = 0.004
Overall (I^2 = 85.36%, p = 0.00);
0
1
2
3
4
5
6
7
Implant revisions / 100 observed component years

Figure Legends

Figure 1 - PRISMA flow diagram of included studies

Figure 2 - Outcomes of UKA by surgical caseload (UKA per surgeon per year)

Figure 3 - Outcomes of UKA by surgical usage (percentage of primary knee arthroplasty that are UKA)

Figure 4 - Outcomes of UKA by combined surgical caseload and usage