

Differences in mortality and complication rates following revision knee arthroplasty performed for urgent versus elective indications

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Keywords

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ABSTRACT

AIM

To compare rates of serious adverse events in patients undergoing revision knee arthroplasty with consideration of the indication for revision (urgent versus elective indications) and compared these with primary arthroplasty and re-revision arthroplasty.

METHODS

Patients undergoing primary knee arthroplasty were identified in the national Hospital Episode Statistics (HES). Subsequent revision and re-revision arthroplasty procedures in the same patients and same knee were identified. The primary outcome was 90-day mortality and a logistic regression model was used to investigate factors associated with 90-day mortality and secondary adverse outcomes including infection (undergoing surgery), pulmonary embolism, myocardial infarction, stroke. Urgent indications for revision arthroplasty were defined as infection or fracture, and all other indications (e.g. loosening, instability, wear) were included in the elective indications cohort.

RESULTS

939,021 primary knee arthroplasty cases were included (939,021 patients) of which 40,854 underwent subsequent revision arthroplasty, and 9,100 underwent re-revision arthroplasty. Revision surgery for elective indications was associated with a 90-day rate of mortality of 0.44% ([135/30,826](#); 95% CI 0.37 to 0.52) which was comparable to primary knee arthroplasty (0.46%; [4,292/939,021](#); 95% CI 0.44 to 0.47). Revision arthroplasty for infection, however, was associated with a much higher mortality of 2.04% ([184/9037](#); 95% CI 1.75 to 2.35; odds ratio [OR] 3.54; 95% CI 2.81 to 4.46), as was revision for periprosthetic fracture at 5.25% ([52/991](#); 95% CI 3.94 to 6.82; OR 6.23; 95% CI 4.39 to 8.85). Higher rates of pulmonary embolism, myocardial infarction, and stroke were also observed in the infection and fracture cohort.

CONCLUSIONS

Patients undergoing revision arthroplasty for urgent indications (infection or fracture) are at high risk of mortality and other serious adverse events in comparison to primary knee arthroplasty and revision arthroplasty for elective indications. These findings will be important for patient consent and shared decision making and should inform service design for this patient cohort.

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- Revision knee arthroplasty performed for patients with urgent indications (infection and fracture) is associated with a higher rate of mortality ([odds ratio 3.5 and 6.2](#) respectively) and serious adverse events in comparison patients with elective indications.
- For patients with elective indications, revision knee arthroplasty is associated with comparable rates of mortality and serious adverse events to primary knee arthroplasty.

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INTRODUCTION

Each year in the United Kingdom more than 100,000 patients undergo primary knee arthroplasty and more than 6,000 patients undergo revision knee arthroplasty.(1) Revision knee arthroplasty is complex surgery and the number and cost of knee revision procedures performed per year is expected to rise.(1–3) In particular, the incidence of knee revision for infection and periprosthetic fracture appear to be rising and these cases represent a significant treatment burden for surgical units.(1,3–6) Whilst the risk of complications following primary knee arthroplasty is well-reported,(7–9) few studies have examined adverse events following revision and re-revision knee arthroplasty and there is a need to understand the association between indications and outcome.

The objective of this study was to compare rates of serious adverse events in patients undergoing primary knee arthroplasty in comparison to revision and re-revision arthroplasty, with consideration of the indication for revision (urgent versus elective indications).

METHODS

Data source and approval

Hospital episode statistics (HES) data was obtained from NHS Digital [following Independent Group Advising on the Release of Data \(IGARD\) approval](#) (application DARS-NIC-68703). [The HES records were](#) linked with the Office for National Statistics (ONS) mortality dataset (national death certificate data). HES contains a record of episodes of hospital care funded by the NHS in England and privately funded care undertaken within NHS hospitals in England.(10)

Procedures

All patients undergoing primary knee arthroplasty in England between April 1, 1997 and March 31, 2017 were identified. Only the first operated knee per patient was included, [by identifying all knee arthroplasty procedures, linked by patient identifier, and including only the first primary arthroplasty procedure](#). Patients under the age of 20 as were excluded [as an atypical and heterogenous case age group and because the number of these cases was felt to be too small for meaningful analysis \(Figure 1\)](#). Patients undergoing revision (first revision) and re-revision arthroplasty procedures (latest revision) to the same knee were identified [using corresponding procedure, side, and patient identifiers](#). Three cohorts were therefore identified and analysed: (1) the primary arthroplasty cohort, (2) the revision arthroplasty cohort, and (3) the re-revision arthroplasty cohort. Cases missing essential data (age, sex) were excluded from the study. Cases missing non-essential data (index of multiple deprivation, ethnicity, rurality) were included except for analyses adjusting for these specific variables. Cases undergoing revision for infection or periprosthetic fracture were identified from corresponding International Statistical Classification of Diseases and Related Health Problems (ICD-10) and Office of Population Censuses and Surveys (OPCS) operation field codes and were defined as “urgent indications” for revision arthroplasty. All other revision procedures were analysed in the elective category, including revision performed for indications such as loosening, instability, wear.

Outcomes

The primary outcome of the study was mortality within 90-days of the arthroplasty procedure. Secondary outcomes were 90-day occurrence of infection (undergoing surgery), pulmonary embolism, myocardial infarction, stroke, lower respiratory tract infection (LRTI), acute kidney injury (AKI), urinary tract infection (UTI), and neurovascular injury respectively. These adverse events were identified by a review of a combination of the twenty ICD-10 diagnosis fields per hospital episode, twenty-four OPCS operation fields per episode, and ONS mortality fields.(11,12) Adverse events identified from the ICD-10 diagnosis fields were: pulmonary embolism (PE), myocardial infarction, stroke, LRTI, AKI, UTI, and neurovascular injury. Infection was defined as open or arthroscopic washout (OPCS fields) with a corresponding ICD-10 infection

code and was also confirmed to match with the site (knee) and laterality (left versus right) of the index procedure using the OPCS site and laterality codes.

Statistical analysis

Descriptive statistics were used to report demographic data. Proportions were reported with 95% confidence intervals corresponding to the proportion of the study sample. For the primary outcome, 90-day mortality, logistic regression methods were used to calculate the odds of mortality in the revision arthroplasty cohort by indication for revision (urgent versus elective as defined above), age, sex, index of multiple deprivation (quintile derived from regional factors in England including average income, employment, education, housing, and crime; 1=least deprived area, 5=most deprived),(13) ethnicity, modified Charlson comorbidity index (Summary Hospital-level Mortality Indicator Specification; derived with a maximum 5-year diagnosis code lookback period),(14–16) obesity, year of treatment, ethnicity, and rurality. Crude odds ratios by each of these respective variables were then adjusted including all the variables in the same model. Stata v15.1 (StataCorp, College Station, Texas, USA) was used to perform all analysis.

Role of the funding source

The sponsors of the study had no role in the design or conduct of the study. All authors take responsibility for the contents of the study and the decision to proceed to publication.

RESULTS

Between 1 April 1997 and 31 March 2017, 1,191,917 primary arthroplasty procedures were performed in 941,524 patients (Figure 1). Of these, after excluding patients under the age of 20-years and non-index procedures (per patient), 939,021 primary arthroplasty procedures (939,021 patients) were included. Of these, 40,854 patients (4.35%; [40,854/939,021](#); 95% CI 4.31 to 4.39) underwent a subsequent revision arthroplasty and 9,100 (0.97%; [9,100/939,021](#); 0.95 to 0.99) underwent a re-revision arthroplasty.

Demographics and indications for revision arthroplasty

The demographics of the cohort and indications for revision arthroplasty (where applicable) are summarised in Table 1. The mean age of patients at the time of primary arthroplasty was 69.8 years (SD 9.62). The mean age of patients at the time of undergoing a revision arthroplasty was 67.6 years (SD 10.25), and 66.2 years (SD 10.2) for re-revision arthroplasty. First time revision arthroplasty was most commonly performed for the defined elective indications (75.5%; [30,826/40,854](#); 95% CI 75.0 to 75.9), followed by infection (22.1%; [9,037/40,854](#); 95% CI 21.7 to 22.5), then fracture (2.43%; [991/40,854](#); 95% CI 2.28 to 2.58). For re-revision cases, the most common indications were again elective (51.5%; [4,682/9,100](#); 95% CI 50.4 to 52.5) but infection represented a greater proportion than first time revision cases (46.4%; [4,224/9,100](#); 95% CI 45.4 to 47.5); fracture rates were comparable (2.13%; [194/9,100](#); 95% CI 1.85 to 2.45). Greater rates of comorbidity and obesity were observed in the revision arthroplasty cohorts, and patients with a greater IMD, urban rurality, and white ethnicity made up a greater proportion of the revision arthroplasty cohorts (Table 1).

Like primary knee arthroplasty (57.6% female; [540,841/939,021](#); 95% CI 57.5 to 57.7), revision arthroplasty was more commonly performed in female patients (54.7%; [22,331/40,854](#); 95% CI 54.2 to 55.1), with a greater proportion of revisions performed for elective indications (56.9%; [17,535/30,826](#); 95% CI 56.3 to 57.4) and fracture (77.6%; [769/991](#); 95% CI 74.9 to 80.2), but a greater proportion of revisions for infection were performed in male patients (55.4%; [5,010/9,037](#); 95% CI 54.4 to 56.5) (Table 1 and Table 2). Re-revision arthroplasty was more commonly performed in male patients (51.8% male; [4,714/9,100](#); 95% CI 50.8 to 52.8) (Table 1)

Adverse outcomes within 90-days: primary arthroplasty versus revision arthroplasty

Rates of adverse outcomes, comparing primary arthroplasty with revision arthroplasty cases and re-revision cases, are summarised in Table 3. The rate of infection within 90-days in the primary arthroplasty cohort was 0.16% ([1,514/939,021](#); 95% CI 0.15 to 0.17), but higher in the first revision arthroplasty cohort at 0.60% ([245/40,854](#); 95% CI 0.53 to 0.68) and the re-revision cohort at 0.57% ([52/9,100](#); 95% CI 0.43 to 0.75). Mortality rates were also higher in the revision cohorts at 0.91% ([371/40,854](#); 95% CI 0.82 to 1.00) in the first revision cohort, and 1.12% ([102/9,100](#); 95% CI 0.91 to 1.36) in the re-revision cohort, in

comparison to 0.46% ([4,292/939,021](#); 95% CI 0.44 to 0.47) in the primary arthroplasty cohort. These differences were driven by high rates of these adverse outcomes in patients undergoing revision for infection and fracture (see below and Table 4).

Pulmonary embolism was recorded at a marginally lower rate in the revision arthroplasty cases (0.61%; [248/40,854](#); 95% CI 0.53 to 0.69) and re-revision cases (0.55%; [50/9,100](#); 95% CI 0.41 to 0.72), in comparison to primary arthroplasty cases (0.74%; [6,951/939,021](#); 95% CI 0.72 to 0.76). Rates of lower respiratory tract infection, acute kidney injury, and urinary tract infection were all higher in the revision and re-revision cases (Table 3). Again, these differences were driven by high rates of these adverse outcomes in patients undergoing revision for the urgent indications (infection and fracture; see below and Table 4).

Rates of stroke and myocardial infarction were similar in all three cohorts. Neurovascular injury was rare but was recorded at a higher rate in re-revision arthroplasty cases (0.15%; [14/9,100](#); 95% CI 0.08 to 0.26) in comparison to primary arthroplasty cases (0.06%; [531/939,021](#); 95% CI 0.05 to 0.06).

Adverse outcomes within 90-days: revision arthroplasty by indication

Rates of adverse outcomes in the revision arthroplasty cohort according to the indication for the revision, are summarised in Table 4.

Revision for “elective” indications (e.g. loosening, instability, wear)

In patients undergoing revision for elective indications, the rate of 90-day mortality was comparable to patients undergoing primary arthroplasty at 0.44% ([135/30,826](#); 95% CI 0.37 to 0.52) versus 0.46% ([4,292/939,021](#); 95% CI 0.44 to 0.47). Rates of other adverse outcomes were also comparable to primary arthroplasty, with the exception of a marginally lower rate of recorded pulmonary embolism (0.54%; [165/30,826](#); 95% CI 0.46 to 0.62) and myocardial infarction (0.27%; [83/30,826](#); 95% CI 0.21 to 0.33) (Table 4).

Revision for infection

Much higher rates of adverse outcomes were reported in patients undergoing revision for the urgent indications (infection or fracture). In patients undergoing revision for infection, further surgery for infection was undertaken within 90-days in 1.99% ([180/9,037](#); 95% CI 1.71 to 2.30). The 90-day mortality rate was also high, at 2.04% ([184/9,037](#); 95% CI 1.75 to 2.35). In a fully adjusted model, the odds of mortality in patients undergoing revision arthroplasty for this indication was 3.54 (95% CI 2.81 to 4.46), in comparison to revision for elective indications (Table 5). Higher rates of pulmonary embolism, myocardial infarction, stroke, lower respiratory tract infection, acute kidney injury, and urinary tract infection were also recorded in comparison to primary arthroplasty and revisions for elective indications (Table 4).

Revision for periprosthetic fracture

Revision arthroplasty undertaken for fracture was associated with higher rates of all adverse events (with the exception of infection and neurovascular injury) than primary arthroplasty and revision arthroplasty for elective indications (Table 4). The 90-day mortality rate in this cohort was 5.25% ([52/991](#); 95% CI 3.94 to 6.82). In a fully adjusted model, the odds of mortality in patients undergoing revision arthroplasty for this indication was 6.23 (95% CI 4.39 to 8.85), in comparison to revision for loosening, instability or wear (Table 5). The rate of pulmonary embolism was 1.51% ([15/991](#); 95% CI 0.85 to 2.48). The rate of acute kidney injury was 6.36% ([63/991](#); 95% CI 4.92 to 8.06).

DISCUSSION

Principal findings

Adverse events are uncommon in patients undergoing primary knee arthroplasty and revision knee arthroplasty for elective indications. For patients undergoing revision for infection or fracture (“urgent” indications), however, rates of adverse events are much higher. Mortality, myocardial infarction, stroke, and acute kidney injury all occur at much higher rates in patients undergoing revision knee arthroplasty for these urgent indications.

Comparison with previous studies

Many of the studies that have evaluated complication rates after revision knee arthroplasty have focussed on patient factors. Potentially modifiable risk factors known to adversely affect outcomes from revision knee arthroplasty are pre-operative anaemia (17), hyponatraemia (18), low albumin (19), low vitamin D (20), and obesity (21). Patients with elective indications for revision knee arthroplasty (e.g. loosening, instability, wear) are typically operated following considerable pre-operative optimisation and scheduling. This approach has been shown to be effective for anaemia (22) and surgical site infections (SSI), with a multi-centre trial currently investigating delivery on a national basis.(23) In contrast, patients with peri-prosthetic fracture almost always present acutely and those with infection typically require more expeditious treatment compared with aseptic indications.

The cohort of patients undergoing urgent revision knee arthroplasty for generally “non-discretionary” indications (~~infection and fracture~~) share features with the cohort of frail, elderly patients presenting with a hip fracture.(24) ~~In the setting of hip fracture, for every 1000 patients operated on after 48 hours, 25 additional patients die within 30 days.(24) The mortality rate reported in the present study for patients undergoing revision for periprosthetic fracture is comparable to the mortality rate for hip fracture patients, and also the rate reported recently for patients undergoing revision hip arthroplasty for periprosthetic femoral fracture.(24,25)~~ There is a balance to be achieved between pre-operative investigation and optimisation and avoidance of unnecessary delays to surgery.(24,26) ~~For hip fracture, surgical units should aim to optimise anaemia, electrolyte disturbances and pneumonia from admission without requiring delay to surgery. Coagulopathies, decompensated heart failure, cardiac arrhythmias, uncontrolled diabetes and sepsis may merit more prolonged optimisation.(26)~~ In the United Kingdom, ~~financial incentives designed to reward~~ high-quality, expedient care for hip fractures ~~has~~ been shown to be effective ~~in improving outcomes~~.(27) A similar approach may be beneficial for revision knee arthroplasty for infection or fracture. The complexity of revision surgery and requirement for a subspecialty trained revision arthroplasty surgeon, however, places further strain on delivery of this complex pathway. Further investigation is needed to determine to what

extent delay to surgery or non-specialist surgeons delivering care for urgent revisions has contributed to the higher observed complication rates here.

When comparing complication rates for revision knee arthroplasty to primary knee arthroplasty, most authors have reported on an unselected cohort. Bohl et al investigated 4911 patients from the American College of Surgeons National Surgical Quality Improvement Program (NSQIP) database and found that patients undergoing revision TKA had higher rates of systemic sepsis, deep surgical site infection (SSI), and organ/space infection compared to primary TKA.(28) There was, however, no difference in rates of pulmonary embolism or deep venous thrombosis. In contrast, we found a significantly increased rate of pulmonary embolism in revisions for periprosthetic fracture, but otherwise similar rates to primary knee arthroplasty. Again, future investigation of the role of delay to surgery will be necessary here. We did not examine incidence of deep venous thrombosis since our analysis was limited to hospital episodes and many cases in the United Kingdom are now diagnosed and treated in the community so would not have been captured.

For prosthetic joint infection (PJI), Boddapati et al used the NSQIP database to compare primary TKA, with aseptic revision TKA and revision TKA for PJI.(29) The rate of any complication was 6.26% for revision TKA compared to 3.54% for primary TKA (OR 1.66).(29) Patients had increased rates of death and respiratory, renal and wound complications in the revision TKA group. This was most marked in revisions for PJI (OR 3.64), who also had increased operative time (+43 minutes) and length of stay (+2.4 days) compared to primary TKA. Zmistowski et al reported a five-fold increase in mortality for revision arthroplasty for PJI from a series of 436 cases of infection and 2342 aseptic revisions.(30) Shahi et al, in comparison, reported a lower two-fold increase in in-hospital mortality for PJI.(31) Staats et al found that, in revisions for aseptic loosening, even one positive Musculoskeletal Infection Society (MSIS) minor criterion was associated with increased risk of re-revision.(32,33) Edmiston et al investigated the effect of patient comorbidities on surgical site infection (SSI) within 90-days of primary and revision hip and knee arthroplasty using the IBM MarketScan and Medicare databases.(34) SSI rates were 15.6% after revision TKA, compared to 2.1% after primary TKA; AIDS, dementia, lymphoma and metastatic cancer were the more important patient-level risk factors for SSIs.(34)

Strengths and limitations

This study represents the largest cohort to report on complications after revision knee arthroplasty. We used observational data from HES, which is used to record all admissions to National Health Service (NHS) hospitals in England. Data on operative procedures and comorbidity from this dataset are used for financial reimbursement, meaning there is a strong incentive for accurate coding. This statement is supported by strong correlation between calculations for the modified Charlson comorbidity index and serious vascular

complications between HES and primary care databases (35,36). Whilst there is known to be some variation in coding completeness in HES over time, coding accuracy is highest for procedures and serious medical events.(35–37) The ONS mortality dataset used in this database for the mortality outcomes is the UK national record of death certificate data, irrespective of where deaths occurs (community or hospital).(38) Direct validation against clinical records for a cohort of this magnitude is not possible due to the resources and identifiable data access that would be required.

We used a 90-day post-operative interval to analyse complications in order to provide a high capture-rate, whilst also being confident that complications related to the procedure under investigation. In contrast, studies using the NSQIP database are limited to reporting 30-day complication rates and miss complications outside of this window.(28) Prescribing records are not included in HES and therefore it is not possible in this database to consider the impact of prescribing (e.g. thromboprophylaxis, antibiotics) on the recorded outcomes, but this was not the purpose of the study. For patients undergoing reoperation rate for infection within 90-days, it should be noted whilst this is an important early patient outcome consideration, this intervention rate does not necessarily reflect the true deep infection rate as microbiological results are not available in HES.

This is the first national database study to differentiate between outcomes following first-time revision versus re-revision arthroplasty. Nearly half of re-revision arthroplasties were for urgent indications (infection 46.4%, fracture 2.1%). This group should be viewed as being at high risk for mortality and serious complications. The present study used ICD-10 codes to determine indication for revision surgery. These codes are input by hospital administrators and have not been validated against surgeon-input codes, such as those found on the National Joint Registry (NJR). Future analysis of the NJR is likely to provide more granularity on reason for revision and procedure type. However, the HES database analysed here has many advantages including facilitating analysis of data over a longer period of time and higher case ascertainment. For comparison, the NJR began recording arthroplasty procedures on 1st April 2003 with 37,794 first-linked revision knee arthroplasty procedures included in their latest report.(1) Revision procedures without modular exchange were not recorded on the NJR until June 2018.(39) For revision procedures, contemporary case ascertainment by the NJR is approximately 90% that of HES.(40)

Conclusion

These findings highlight the burden of complications associated with revision knee arthroplasty. They will inform shared decision making for patients considering revision knee arthroplasty for elective indications, and also the consent process for patients with infection or periprosthetic fracture. Patients presenting with infection of a knee arthroplasty or a periprosthetic fracture are at very high risk of adverse events. It is therefore imperative that acute hospital services and tertiary referral centres caring for these patients are

appropriately supported to ensure they are treated with the appropriate urgency and an anticipation for increased care requirements.

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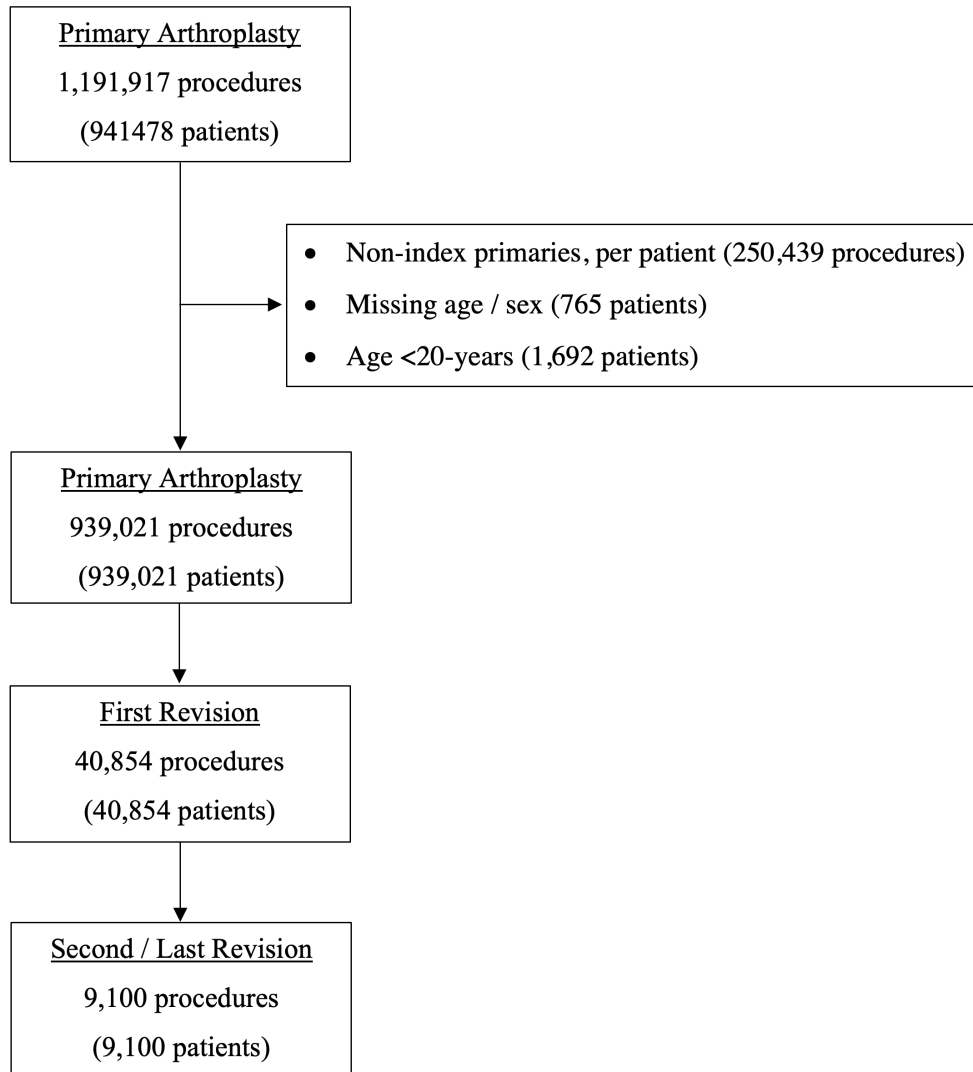
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FIGURES

FIGURE 1: Case selection



TABLES

TABLE 1: Demographics primary vs revision vs re-revision cases

	Primary Knee		1 st Revision Knee		2 nd /Last Revision Knee	
	n	%	n	%	n	%
All procedures						
Total	939,021	100.0	40,854	100.0	9,100	100.0
Revision indication						
Elective indications	-	-	30,826	75.45 (75.03, 75.87)	4,682	51.45 (50.42, 52.48)
Infection	-	-	9,037	22.12 (21.72, 22.53)	4,224	46.42 (45.39, 47.45)
Fracture	-	-	991	2.43 (2.28, 2.58)	194	2.13 (1.85, 2.45)
Sex						
Male	398,180	42.40 (42.30, 42.50)	18,523	45.34 (44.86, 45.82)	4,714	51.80 (50.77, 52.83)
Female	540,841	57.60 (57.50, 57.70)	22,331	54.66 (54.18, 55.14)	4,386	48.20 (47.17, 49.23)
Age group (years)						
20-39	3,135	0.33 (0.32, 0.35)	215	0.53 (0.46, 0.60)	69	0.76 (0.59, 0.96)
40-59	131,982	14.06 (13.99, 14.13)	8,480	20.76 (20.36, 21.15)	2,194	24.11 (23.23, 25.00)
60-79	658,115	70.09 (69.99, 70.18)	27,196	66.57 (66.11, 67.03)	6,005	65.99 (65.01, 66.96)
80+	145,789	15.53 (15.45, 15.60)	4,963	12.15 (11.83, 12.47)	832	9.14 (8.56, 9.75)
Modified Charlson comorbidity index						
0	702,013	74.76 (74.67, 74.85)	28,825	70.56 (70.11, 71.00)	6,151	67.59 (66.62, 68.55)
1 - 15	228,374	24.32 (24.23, 24.41)	11,516	28.19 (27.75, 28.63)	2,788	30.64 (29.69, 31.60)
16 - 30	8,250	0.88 (0.86, 0.90)	490	1.20 (1.10, 1.31)	155	1.70 (1.45, 1.99)
31 - 50	384	0.04 (0.04, 0.05)	23	0.06 (0.04, 0.08)	6	0.07 (0.02, 0.14)
Obesity						
No	854,047	90.95 (90.89, 91.01)	36,632	89.67 (89.37, 89.96)	8,003	87.95 (87.26, 88.61)
Yes	84,974	9.05 (8.99, 9.11)	4,222	10.33 (10.04, 10.63)	1,097	12.05 (11.39, 12.74)
IMD						
1	203,950	21.72 (21.64, 21.80)	8,082	19.78 (19.40, 20.17)	1,701	18.69 (17.90, 19.51)
2	210,515	22.42 (22.33, 22.50)	8,637	21.14 (20.75, 21.54)	1,982	21.78 (20.94, 22.64)
3	203,433	21.66 (21.58, 21.75)	8,814	21.57 (21.18, 21.98)	1,953	21.46 (20.62, 22.32)
4	171,505	18.26 (18.19, 18.34)	7,928	19.41 (19.02, 19.79)	1,786	19.63 (18.81, 20.46)
5	142,117	15.13 (15.06, 15.21)	7,216	17.66 (17.29, 18.04)	1,640	18.02 (17.24, 18.83)
Missing	7,501	-	177	-	38	-
Rurality						
Urban	715,008	76.14 (76.06, 76.23)	31,588	77.32 (76.91, 77.72)	6,952	76.40 (75.51, 77.27)
Rural	222,052	23.65 (23.56, 23.73)	9,236	22.61 (22.20, 23.02)	2,144	23.56 (22.69, 24.45)
Missing	1,961	-	30	-	4	-
Ethnicity						
White	867,737	92.41 (92.35, 92.46)	38,675	94.67 (94.44, 94.88)	8,632	94.86 (94.38, 95.30)
Asian	29,876	3.18 (3.15, 3.22)	972	2.38 (2.23, 2.53)	236	2.59 (2.28, 2.94)
Black	10,472	1.12 (1.09, 1.14)	615	1.51 (1.39, 1.63)	134	1.47 (1.24, 1.74)
Mixed	2,077	0.22 (0.21, 0.23)	100	0.24 (0.20, 0.30)	22	0.24 (0.15, 0.37)
Other	4,869	0.52 (0.50, 0.53)	190	0.47 (0.40, 0.54)	43	0.47 (0.34, 0.64)
Missing	23,990	-	302	-	33	-

TABLE 2: Demographics for revision cohort, by revision indication:

	Elective indications		Infection		Fracture	
	n	%	n	%	n	%
All procedures						
Total	30,826	100.0	9,037	100.0	991	100.0
Sex						
Male	13,291	43.12 (42.56, 43.67)	5,010	55.44 (54.41, 56.47)	222	22.40 (19.84, 25.13)
Female	17,535	56.88 (56.33, 57.44)	4,027	44.56 (43.53, 45.59)	769	77.60 (74.87, 80.16)
Age group (years)						
20-39	165	0.54 (0.46, 0.62)	46	0.51 (0.37, 0.68)	4	0.40 (0.11, 1.03)
40-59	6,916	22.44 (21.97, 22.91)	1,459	16.14 (15.39, 16.92)	105	10.60 (8.75, 12.68)
60-79	20,582	66.77 (66.24, 67.29)	6,101	67.51 (66.53, 68.48)	513	51.77 (48.60, 54.92)
80+	3,163	10.26 (9.92, 10.60)	1,431	15.83 (15.09, 16.60)	369	37.24 (34.22, 40.33)
Modified Charlson comorbidity index						
0	22,445	72.81 (72.31, 73.31)	5,779	63.95 (62.95, 64.94)	601	60.65 (57.53, 63.70)
1 - 15	8,101	26.28 (25.79, 26.77)	3,056	33.82 (32.84, 34.80)	359	36.23 (33.23, 39.31)
16 - 30	264	0.86 (0.76, 0.97)	199	2.20 (1.91, 2.53)	27	2.72 (1.80, 3.94)
31 - 50	16	0.05 (0.03, 0.08)	3	0.03 (0.01, 0.10)	4	0.40 (0.11, 1.03)
Obesity						
No	27,775	90.10 (89.76, 90.43)	7,966	88.15 (87.46, 88.81)	891	89.91 (87.86, 91.71)
Yes	3,051	9.90 (9.57, 10.24)	1,071	11.85 (11.19, 12.54)	100	10.09 (8.29, 12.14)
IMD						
1	6,116	19.84 (19.40, 20.29)	1,779	19.69 (18.87, 20.52)	187	18.87 (16.48, 21.45)
2	6,516	21.14 (20.68, 21.60)	1,891	20.93 (20.09, 21.78)	230	23.21 (20.61, 25.97)
3	6,678	21.66 (21.20, 22.13)	1,929	21.35 (20.50, 22.21)	207	20.89 (18.40, 23.55)
4	6,002	19.47 (19.03, 19.92)	1,735	19.20 (18.39, 20.03)	191	19.27 (16.86, 21.87)
5	5,391	17.49 (17.07, 17.92)	1,655	18.31 (17.52, 19.13)	170	17.15 (14.86, 19.65)
Missing	123	-	48	-	6	-
Rurality						
Urban	23,958	77.72 (77.25, 78.18)	6,897	76.32 (75.43, 77.19)	733	73.97 (71.11, 76.67)
Rural	6,846	22.21 (21.75, 22.68)	2,133	23.60 (22.73, 24.49)	257	25.93 (23.23, 28.78)
Missing	22	-	7	-	1	-
Ethnicity						
White	29,286	95.00 (94.76, 95.24)	8,444	93.44 (92.91, 93.94)	945	95.36 (93.86, 96.58)
Asian	632	2.05 (1.89, 2.21)	313	3.46 (3.10, 3.86)	27	2.72 (1.80, 3.94)
Black	453	1.47 (1.34, 1.61)	150	1.66 (1.41, 1.94)	12	1.21 (0.63, 2.11)
Mixed	73	0.24 (0.19, 0.30)	25	0.28 (0.18, 0.41)	2	0.20 (0.02, 0.73)
Other	144	0.47 (0.39, 0.55)	43	0.48 (0.34, 0.64)	3	0.30 (0.06, 0.88)
Missing	238	-	62	-	2	-

TABLE 3: 90-day adverse outcomes primary vs revision vs re-revision cases

	Primary Knee		1 st Revision Knee		2 nd /Last Revision Knee	
90-day outcomes	n (/939,021)	% (95% CI)	n (/40,854)	% (95% CI)	n (/9,100)	% (95% CI)
Mortality	4292	0.46 (0.44, 0.47)	371	0.91 (0.82, 1.00)	102	1.12 (0.91, 1.36)
Infection	1514	0.16 (0.15, 0.17)	245	0.60 (0.53, 0.68)	52	0.57 (0.43, 0.75)
Pulmonary embolism	6951	0.74 (0.72, 0.76)	248	0.61 (0.53, 0.69)	50	0.55 (0.41, 0.72)
Myocardial infarction	3350	0.36 (0.34, 0.37)	143	0.35 (0.30, 0.41)	32	0.35 (0.24, 0.50)
Stroke	2191	0.23 (0.22, 0.24)	101	0.25 (0.20, 0.30)	28	0.31 (0.20, 0.44)
Lower respiratory infection	14506	1.54 (1.52, 1.57)	1013	2.48 (2.33, 2.63)	246	2.70 (2.38, 3.06)
Acute kidney injury	7859	0.84 (0.82, 0.86)	747	1.83 (1.70, 1.96)	228	2.51 (2.19, 2.85)
Urinary tract infection	11906	1.27 (1.25, 1.29)	865	2.12 (1.98, 2.26)	228	2.51 (2.19, 2.85)
Neurovascular injury	531	0.06 (0.05, 0.06)	31	0.08 (0.05, 0.11)	14	0.15 (0.08, 0.26)

TABLE 4: 90-day adverse outcomes for revision cohort by revision indication

	Elective indications		Infection		Fracture	
90-day outcomes	n (/30,826)	% (95% CI)	n (/9,037)	% (95% CI)	n (/991)	% (95% CI)
Mortality	135	0.44 (0.37, 0.52)	184	2.04 (1.75, 2.35)	52	5.25 (3.94, 6.82)
Infection	60	0.19 (0.15, 0.25)	180	1.99 (1.71, 2.30)	5	0.50 (0.16, 1.17)
Pulmonary embolism	165	0.54 (0.46, 0.62)	68	0.75 (0.58, 0.95)	15	1.51 (0.85, 2.48)
Myocardial infarction	83	0.27 (0.21, 0.33)	52	0.58 (0.43, 0.75)	8	0.81 (0.35, 1.58)
Stroke	57	0.18 (0.14, 0.24)	35	0.39 (0.27, 0.54)	9	0.91 (0.42, 1.72)
Lower respiratory infection	489	1.59 (1.45, 1.73)	424	4.69 (4.26, 5.15)	100	10.09 (8.29, 12.14)
Acute kidney injury	257	0.83 (0.74, 0.94)	427	4.73 (4.30, 5.18)	63	6.36 (4.92, 8.06)
Urinary tract infection	360	1.17 (1.05, 1.29)	380	4.20 (3.80, 4.64)	125	12.61 (10.61, 14.84)
Neurovascular injury	20	0.06 (0.04, 0.10)	10	0.11 (0.05, 0.20)	1	0.10 (0.00, 0.56)

TABLE 5: Odds of mortality in revision cohort by patient demographics and revision indication

	Crude Odds Ratio (95% CI)	Adjusted Odds Ratio (95% CI)
Revision indication		
Elective indications	1.00	1.00
Infection	139.27 (111.54, 173.90)	3.54 (2.81, 4.46)
Fracture	374.98 (271.24, 518.40)	6.23 (4.39, 8.85)
Sex		
Male	1.00	1.00
Female	0.76 (0.62, 0.93)	0.82 (0.66, 1.03)
Age group (years)		
20-39	-	-
40-59	1.00	1.00
60-79	4.18 (2.27, 7.70)	3.81 (2.06, 7.04)
80+	27.24 (14.84, 50.02)	21.25 (11.49, 39.29)
Year of procedure		
Per year	1.03 (1.01, 1.05)	1.01 (0.99, 1.04)
Modified Charlson comorbidity index		
0	1.00	1.00
1 - 15	1.97 (1.60, 2.44)	1.62 (1.30, 2.01)
16 - 30	6.76 (4.31, 10.59)	3.59 (2.23, 5.75)
31 - 50	6.27 (0.84, 46.58)	-
Obesity		
No	1.00	1.00
Yes	15.63 (10.41, 23.48)	0.75 (0.50, 1.15)
Index of multiple deprivation (quintile)		
1 = least	1.00	1.00
2	1.09 (0.79, 1.49)	1.12 (0.81, 1.55)
3	1.13 (0.82, 1.54)	1.13 (0.82, 1.57)
4	1.24 (0.90, 1.71)	1.19 (0.85, 1.66)
5 = most	1.20 (0.85, 1.69)	1.10 (0.77, 1.58)
Rurality		
Urban	1.00	1.00
Rural	1.04 (0.82, 1.32)	1.00 (0.77, 1.29)
Ethnicity		
White	1.00	1.00
Asian	1.16 (0.68, 1.98)	1.42 (0.81, 2.48)
Black	-	-
Mixed	1.00 (0.00, 0.00)	1.00 (0.00, 0.00)
Other	0.51 (0.07, 3.61)	0.75 (0.10, 5.46)

Odds ratios were also adjusted by geographic rurality and ethnicity (no significant differences).

- = no cases