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Longitudinal rates, patient risk factors, and economic impact of superficial and deep incisional surgical site infection (SSI) following primary and revision total hip arthroplasty: a US retrospective commercial claims database analysis

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Abstract

Background: Longitudinal rates, risk factors, and costs of superficial and deep incisional surgical site infection (SSI) were evaluated six months after primary (pTHA) and revision total hip replacement (rTHA).

Methods: Patients, following pTHA or rTHA, were identified from January 1, 2016-March 31, 2018, utilizing the IBM® MarketScan® administrative claims databases. Kaplan-Meier survival curves evaluated time to SSI over six months. Cox proportional hazard models evaluated SSI risk factors. Generalized linear models estimated SSI costs up to 12 months.

Results: The total cohort included 17,514 pTHA patients (mean [SD] age 59.6 [10.1] years, 50.2% female; 66.4% commercial insurance), and 2,954 rTHA patients (61.2 [12.0] years, 52.0% female; 48.6% commercial insurance). Deep and superficial SSI at 6-months post-op affected 0.30% (95%CI: 0.22%-0.39%) and 0.67% (95%CI: 0.55%-0.79% of patients in the pTHA, and 8.9% (95%CI: 7.8%-10.0%) and 4.8% (95%CI: 4.0%-5.6%) of patients in the rTHA cohorts. Hazards for SSI were related to patient comorbidities which included diabetes, obesity, renal failure, pulmonary or circulatory disorders, and depression. The adjusted average all-cause incremental commercial costs associated with postoperative infection ranged from $21,434-$42,879 for superficial incisional SSI and $53,884-$76,472 for deep incisional SSI, over a 12-month postoperative assessment period.

Conclusions: The SSI rate after revision total hip arthroplasty (rTHA) was nearly 9% compared with 1.0% after primary arthroplasty (pTHA). The risk of infection was influenced by several comorbid risk factors. The incremental cost associated with SSIs was substantial.

Introduction

More than 300,000 hip replacement procedures are undertaken annually in the United States.[1-3] The number of primary and revision total joint replacement (TJA) including hip arthroplasty are expected to increase by 2030 with an ageing population and an increasing prevalence of arthritis and comorbid conditions.[4-6] While THR is effective in improving quality of life and low morbidity and mortality, surgical site infection (SSI) poses a significant, and expensive, complication of this procedure.

Postoperative peri-joint infections have four inter-related risk factors which include: (1) microbial-related factors which involve bacterial virulence and antimicrobial resistance; (2) multiple comorbidities, such as obesity, diabetes mellitus, and a history of corticosteroid therapy; (3) intra-operative risk factors which include the perioperative surgical team, operative technique, organization and management, and the operating room environment; and (4) post-operative care and post-operative wound management. Although superficial incisional SSIs after THR may be amenable to local wound treatment with debridement and antiseptic dressings and antibiotic therapy, infection may extend beyond the subcutaneous layer to involve deeper tissue (fascial) layers. These deep incisional SSIs are a risk for development of periprosthetic infections which in most cases will require device removal or, at the least, prolonged intervention and debridement.[6,7]

The reported incidence of SSI after primary THA (pTHA) and rTHA) ranges from 0.4% to 8.6%, depending upon the patient populations evaluated, the type of surgical procedure, and the definition of SSI.[8-10] In a previous analysis of 163,547 THRs we reported that SSI rates were 8.6% for rTHA compared with 2.1% for pTHA. Comorbid risks associated with the greatest adjusted effect on SSI after pTHA were paralysis, alcohol abuse, obesity, diabetes, depression, coagulopathy, chronic pulmonary disease, fluid electrolyte disorder, uncontrolled hypertension, rheumatoid arthritis, congestive heart failure, smoking, and renal failure. Comorbidities which had the greatest impact on SSI following rTHA were metastatic cancer, congestive heart failure, blood loss anemia, coagulopathy, weight loss, alcohol abuse, deficiency anemia, obesity, uncontrolled hypertension, diabetes, and fluid electrolyte disorder.[11] The purpose of the

current study was to build upon these findings by conducting a longer durational (180-day) longitudinal analysis utilizing the same database to more accurately determine the time of SSI presentation after rTHA and if associated risk factors differed in relation to the time of SSI presentation. The current analysis also reports the all-cause incremental costs of pTHA and rTHA patients associated with superficial and deep incisional SSI.

Methods

Data Sources

This analysis was designed as a retrospective cohort study using the IBM® MarketScan® Commercial Claims and Encounters (CCAE), Medicare Supplemental and Coordination of Benefits (MDCR), and Multi-State Medicaid (MDCD) databases. The CCAE contains information on insured individuals who are under the age of 65. The Medicare database includes information for individuals who are 65 years or older. Data for the CCAE and Medicare databases are collected from over 300 large, self-insured US employers and over 25 US health plans. The databases comprise enrollment information, demographics, and adjudicated health insurance claims (e.g., inpatient, outpatient, and outpatient pharmacy).

A standard extract from these databases consists of three files: (1) an enrollment file which includes patient sociodemographic and health insurance payer type information; (2) a medical file which includes detailed records for hospital in- and outpatient admissions and services across different facilities of care captured with an international classification of disease (ICD)-9 and ICD-10 diagnosis (clinical modification ((CM)) and procedure (procedure coding system (PCS)) codes and Common Procedural Terminology (CPT) codes; and (3) a drug file (pharmacy claims). The files are linkable, based on an encrypted patient identification number. Institutional Review board approval was not necessary to conduct this study, as data within these databases are de-identified and comply with Health Insurance Portability and Accountability Act (HIPAA) regulations.

Patient Population

Patients in the database who underwent pTHA or rTHA (identified using ICD-10-PCS codes or CPT-4 codes) between January 1, 2016, and March 31, 2018, in either outpatient or inpatient settings of care were considered for inclusion. The date of hospitalization for THR was defined as the index date. Patients were included if they were 18 or older and continuously enrolled for at least 12 months before and 180 days after index THR. Patients having a knee procedure undertaken from 12 months pre-, to 2 years post-index, or the contralateral hip performed within 6 months of index or having any femoral fractures at time of index surgery were excluded. These exclusions were designed to avoid including other potential sources of SSI in the analyses. For the primary cohort (pTHA), additional exclusion criteria included: non-elective cases and the presence of deep or superficial incisional SSI at the time of surgery, and up to 2 days post-surgery. This exclusion criterion was designed to avoid including existing infection in the SSI analysis.

Outcomes Evaluated

Demographic characteristics included age, sex, and health insurance type (i.e., commercial, Medicare, or Medicaid). Baseline clinical characteristics included the comorbidities prior to THR assessed using the Elixhauser Comorbidity Index (ECI). The ECI estimates an aggregate measure of comorbidity using 31 dimensions and has been shown to be associated with risk of mortality and health care utilization.[12, 13] For each patient, the occurrence of SSI within 180 days after pTHA or rTHA was evaluated using ICD-10-CM codes. The primary outcome was occurrence of deep incisional infection (defined as a new diagnosis for deep incisional infection or osteomyelitis) from 2 to 180 days postoperatively. Secondary outcomes included the occurrence of superficial SSI, and incremental, all-cause healthcare costs associated with deep and superficial SSI, evaluated from the perspective of the insurer, at 6-, and 12-months post-index. For the evaluation of deep incisional infection following rTHA, a subgroup analysis was conducted to analyze the occurrence of deep infection from 2-180 days postoperatively, *excluding* patients with a diagnosis of deep incisional infection up to one year prior to

the rTHA, This sub-group analysis was designed to evaluate the risk of deep incisional infection in patients having their hip replacement revised for non-infection related causes.

Statistical Analyses

Descriptive statistics including means and standard deviations (SDs) for all continuous variables and proportions for categorical variables were performed to describe all variables in the dataset. Analyses were performed separately for pTHR and rTHR patients. Time to superficial and deep incisional SSI over six months was represented with Kaplan-Meier survival curves. Cox proportional hazard models examined the effects of preoperative patient characteristics (demographics and pre-existing comorbid factors) and surgical characteristics (year of surgery) on the hazard of superficial or deep incisional SSI. Hazard ratios (HRs), 95% confidence intervals (CIs), and p-values were computed. Generalized linear models with gamma distribution and log links estimated the adjusted all-cause incremental cost of superficial and deep incisional SSI. All costs were adjusted to 2021 US dollars using the Bureau of Labor Statistics (BLS) consumer price-index.[14]

Results

A total of 17,514 pTHA patients and 2,954 rTHA patients were included in the analyses.

Patient Baseline Demographic and Clinical Characteristics

Baseline demographic, clinical characteristics and comorbid risks for patients with pTHA and rTHA are presented in **Table 1**. Mean ages (SD) were 59.6 (10.1) years for pTHA and 61.2 (12.0) years for rTHA, with a large proportion of patients aged 55 to 64 (50.1% pTHA and 40.6% rTHA). Females accounted for 50.2% of pTHA patients and 52.0% of rTHA patients.

For pTHA, approximately two-thirds of patients had commercial insurance (66.4%) and the remainder had Medicare (18.8%) or Medicaid (14.8%) insurance. For

rTHA patients, approximately half had commercial insurance (48.6%) and approximately one-quarter each had Medicare (27.1%) or Medicaid (24.3%) insurance.

Mean (SD) ECI scores were higher among patients with rTHA (3.6 [2.7]) compared with patients in the pTHA cohort (2.1 [1.9]). Compared to pTHA, patients in the rTHA cohort were also more likely to have an ECI of 5 or greater (pTHA: 10.2%, rTHA: 29.9%). All key comorbid risk factors were more prevalent in the rTHA patient population compared to the pTHA cohort. For example, for pTHA: complicated hypertension, obesity and complicated diabetes affected 4.5%, 18.3% and 6.6% patients. For rTHA, the same comorbidities affected 10.8%, 26.5% and 12.2% patients.

Superficial and Deep Incisional SSI Rates and Timing

Deep and superficial SSI affected 0.30% (95%CI: 0.22%-0.39%) and 0.67% (95%CI: 0.55%-0.79% of patients in the pTHA, and 8.9% (95%CI: 7.8%-10.0%) and 4.8% (95%CI: 4.0%-5.6%) of patients in the rTHA cohorts. For revision THA cases that did not have an infection at time of revision (subgroup analysis), the rate of deep SSI post-index reached 6.0% (95%CI: 5.1%-6.9%). Key demographic and comorbid characteristics of patients with and without infection are shown in **Table 2**. Age did not change between patients with and without infection. There were fewer females in the deep SSI group compared to the no infection groups (for pTHA: 49.1% vs 50.2%; for rTHA: 43.8% vs 52.7%). Mean ECI was highest in the deep SSI cohorts, compared to the no infection groups. The percentage of patients with an ECI of 5 or greater was also larger in the deep SSI group compared to the no infection group (for pTHA: 22.6% vs 10.1% - for rTHA: 57.8% vs 26.5%). Rates of individual comorbidities, as a function of infection outcome, are shown in **Table 3**. As expected, therefore, chronic conditions were far more prevalent in the deep SSI vs. the no infection cohorts, except for hypothyroidism, which did not follow any trends. For many chronic conditions, patients with deep SSI following rTHA also presented with greater rates of comorbidities compared to patients with deep SSI following pTHA. For example: rTHA-deep SSI patients had a 38.6% obesity rate, compared to 34% in the pTHA-deep SSI cohort. The rate of complicated hypertension also reached 18.3% of the rTHA-deep SSI cohort,

versus 7.5% of the pTHA-deep SSI cohort.The time to infection kaplan-meier graphs are shown in the **Supplemental Figures S1-S4.**

Patient Characteristics Associated with SSI

Forest plots of hazard ratios for deep and superficial SSI following primary and revision THA are shown in Figures 1 – 5. As shown in **Figure 1**, none of the patient demographic or comorbidities at time of pTHA was strongly associated with an increased hazard for superficial SSI. Patients on Medicaid had a slightly increased, but not significant, hazard for superficial SSI (hazard ratios (HR) for Medicaid vs Commercially-insured patients: 1.57 (95%CI: 0.94-2.64). The HR for superficial infection also increased with increasing ECI, but even for patients with an ECI score of 5 or above, the HR was not significant (HR: 2.58 (95%CI: 0.87-7.66)). Complicated diabetes and hypothyroidism had non-significant, but elevated hazard ratios (HR) (complicated diabetes: HR = 1.65 (95%CI: 0.92-2.93 – hypothyroidism: HR = 1.57 (95%CI: 0.97-2.55). The HR for deep SSI following pTHA are shown in **Figure 2**. Unlike superficial SSI, many comorbidities were significantly associated with increased risk of deep SSI, specifically: blood loss anemia (HR: 4.74 (95%CI: 1.07-21.11), renal failure (HR: 3.20 (95%CI: 1.25-8.20)), complicated diabetes (HR: 3.02 (95%CI: 1.13-8.09)), depression (HR: 2.25 (95%CI: 1.15-4.37)), rheumtoid arthritis (HR: 2.32 (95%CI: 1.10-4.87), cardiac arrythmia (HR: 2.27 (95%CI: 1.14-4.53) and obesity (HR: 1.99 (95%CI: 1.05-3.77). For patients undergoing rTHA: very few variables showed significant association for superficial SSI, as shown on **Figure 3**. Coagulopathy (HR: 1.86 (95% CI: 1.05-3.27) and obesity (HR: 1.47 (95%CI: 1.01-2.16)) showed significantly increased HR. All other comorbidities or demographic factors were not associated with increased hazards for superficial SSI. For deep SSI following rTHA, comorbidities mattered, as shown in **Figure 4**. Patients with an ECI of 5 or above had a HR of 3.76 (95%CI: 1.47-9.62). Individual comorbidities associated with increased hazard for deep SSI following rTHA included: fluid and electrolyte disorders (HR: 1.84 (95%CI: 1.37-2.49), complicated diabetes (HR: 1.48 (95%CI: 1.07-2.03), plumonary circulation disorders (HR: 1.67 (95%CI: 1.08-2.58), and obesity (HR: 1.34 (95%CI: 1.01-1.77). A preliminary analysis suggested that the risk of developing a new, deep SSI, following rTHA, was greater in

males compared to female (HR: 1.62 (95%CI: 1.24 – 2.13), and individuals with pulmonary ciruclation disorders (HR: 2.05 (95%CI: 1.20-3.51), depression (HR: 1.84 (95%CI: 1.28-2.65), or fluid and electrolyte disorders (HR: 1.63 (95%CI: 1.10-2.40). The hazard ratio in patients with obesity remained elevated, but not significant (HR: 1.36 (95%CI: 0.96-1.93), **Figure S5**. Finally, the demographic and comorbid characteristics of patients treated with primary or revision total hip arthroplasty (pTHA or rTHA), with superficial infection (SI), deep infection (DI), or no infection (NI) is presented in supplemental **Table S1**.

Costs Associated with SSI

Adjusted all-cause incremental costs associated with superficial and deep incisional SSIs, compared with patients not having an SSI, were available for patients with commercial insurance over 6 and 12 months after pTHA or rTHA. For patients with pTHA, the following average incremental cost of care were incurred when infection was reported: superficial incisional SSI: 6 month costs $21,434 [95%CI: $8,615 - $34,252] and 12 month costs $34,958 [95%CI: $11,163 - $58,753]; deep incisional SSI: 6 month costs $54,521 [95%CI: $7,093 - $101,949] and 12 month costs $76,472 [95%CI: $4,927 - $148,017]). For patients with rTHA: the costs were as follows: superficial SSI 6 month costs $38,519 [95%CI: $13,845 - $63,192] and 12 month costs $42,879 [95%CI: $15,575 - $70,184]; deep incisional SSI: 6 month costs $53,884 [95%CI: $29,636 - $78,131] and 12 month costs $55,605 [95%CI: $21,516 - $89,695]).

Discussion

The current analysis found that SSI – deep and superficial - occurred more commonly after rTHA compared with pTHA. Although patients with pTHA had a low risk of deep (0.3%) and superficial incisional SSI (0.6%), patients with rTHA had a higher risk of deep (8.9%) and superfical (4.8%) SSIs. The rates of SSI after rTHA observed in this study were higher than those of our previously published analysis, which found that SSI rates were 8.6% after rTHA and 2.1% after pTHA.[11] The differences in rates of SSI may be due to the inclusion of Medicaid patients in this study, the differences in timing of data collection (2016-Q12018 for the current analysis compared with 2009-2015 for

the previous analysis), and the differences in duration of follow-up for the studies (180 days for the current study compared with 90 days for the previous analysis). Nevertheless, the rate of SSI is still high and evidence-based consensus guidelines on prevention of SSI are heterogeneous. Preoperative patient optimization prior to total joint replacement for high risk patients can significantly decrease SSI risk as well as improving surgical outcomes and patient care.[16,17]

This analysis demonstrates that risk factors for SSI were related to patient comorbidities, including diabetes, obesity, renal failure, pulmonary circulatory disorders, and depression. While these results suggest a relatively small number of factors related to adverse patient outcomes, they are consistent with our previous analyses of the comorbidities associated with THA SSI.[11]

The current study also found that a pTHA conducted in 2017 (compared with 2016) was associated with a lower risk of deep incisional SSI. There was also a trend for lower risk of deep SSI in 2018, but the difference was not statistically significant; presumably due to the smaller sample size studied in 2018 as only patients after THA within the first three months of the year were included to enable adequate follow-up data post-THA. The findings of a decreasing trend of SSIs in more recent years are consistent with a recent study evaluating SSI with rTHA using the National Surgical Quality Improvement Program (NSQIP) database.[18] There was a trend towards decreasing SSIs nationwide between 2011 and 2016, again emphasizing the benefits from pre- and post-operative infection preventative strategies.[18] Deep incisional SSI rates also reflected a marked improvement, specifically between 2014 and 2016.[18] However, these findings may also be due to changes in coding practices or documentation of infection as hospital infection rates have become more heavily scrutinized in recent years.[19] Furthermore, Medicare non-payment penalties have been instituted in an effort to reduce the incidence of hospital-acquired infections, including selective SSI.[20]

Finally, the current study suggested that male sex was associated with an increased risk of deep SSI after rTHA. The reason for this finding is unclear but aligns with findings from other studies, including our prior investigation.[10,11,21,22] It is also

possible that male sex is linked to other unmeasured variables and that these results are confounded.

The choice between using logistic regression models or Cox proportional hazards models for epidemiologic association studies is primarily based on the design of the study. Cox proportional hazards models are the recommended models if follow-up data are available as they have more statistical power than logistic regression models.[23] This is because the Cox proportional hazards models take account of the time until events occur. To our knowledge, no other study has compared these models in determing the factors associated with incisional SSI after THA.

The analysis also found that the adjusted average all-cause incremental cost associated with SSI is substantial. The adjusted average all-cause incremental commercial costs ranged from $21,434-$42,879 for superficial incisional SSI and $53,884-$76,472 for deep incisional SSI, varying with the time horizon. A substantial proportion of the costs were incurred by 6 months but costs did increase from 6 to 12 months. We focused our cost analysis on the commercial cohort for multiple reasons; the Medicare database does not include all Medicare eligible patients; only those with supplemental insurance provided by the worker's employer. As for Medicaid: data is provided by a small proportion of US states varying from year to year, and may be subject to delayed reimbursement.

The present analysis evaluated, within a the real-world setting, the risk of SSI after pTHA and rTHA. The study used an administrative claims database, enabling an robust analysis of large numbers of patients. However, the results of the study must also be seen in light of its limitations, including that the observational design makes it difficult to draw causal inferences. Potential coding errors and misclassifications within the databases could not be identified and results may therefore lead to under-reported or missing diagnoses based on patients' choice (not to seek care) or access challenges which could not be captured. The findings from this database study are generalizable to similar populations with pTHA and rTHA. This study evaluated the risk of all-cause revisions only and did not analyze the specific cause for the revision.

Conclusion

This real-world data study found that SSI occurred most commonly after rTHR compared with pTHA and among patients with significant co-morbid risks including diabetes, obesity, renal failure, pulmonary circulatory disorders, and depression. Furthermore the costs associated with these infections, whether primary total hip replacement or revision represent a substantial economic cost to the healthcare system.

Although orthopedic (device-related) infections represent a significant cost to patients and the healthcare system, the evolution of evidence-based interventions offer a solution which might mitigate risks. An effective orthopedic care bundle must be scientifically sound (using a level IA evidence base), supported by peer-review, and free of dogmatic surgical practice. One systematic review has documented that introduction of a surgical care bundle was effective in reducing *Staphylococcus aureus* infections after major cardiac and orthopedic procedures.[24] A large cohort analysis has documented the clinical efficacy of a four-component surgical care bundle in improving the clinical outcome of hip arthroplasty.[25] It is proposed that the development of evidence based care bundles and enhanced recovery after surgery (ERAS) protocols could have a significant impact on improving SSI following hip replacement surgery. This benefit has been documented in a systematic review and meta-analysis in which it was found that ERAS significantly reduced the length of stay and incidence of complications in patients after total hip replacement.[26] Finally, our current efforts to improve clinical outcomes currently focuses on collecting data on relevant comorbid risk to which we can then apply evidence-based mitigation strategies. However, it has been recently suggested that failure to reduce the risk of adverse surgical outcome, including incisional SSIs, does not reflect a lack of real-world clinical data but rather a failure of key stakeholders to insure those adequate institutional resources are in-place to validate institutional compliance of effective evidence-based mitigation strategies.[27]

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Figure Legends:

Figure 1: Hazard ratios of demographic and comorbid variables for superficial SSI following primary THA.

Figure 2: Hazard ratios of demographic and comorbid variables for deep SSI following primary THA.

Figure 3: Hazard ratios of demographic and comorbid variables for superficial SSI following revision THA.

Figure 4: Hazard ratios of demographic and comorbid variables for deep SSI following revision THA.

Table 1. Baseline demographic and clinical characteristics and comorbidities for patients undergoing primary and revision THA. *Data shown: N (% of total cohort), or if indicated: mean (SD)*

Variables	Primary THA	Revision THA
All	17,514	2,954
Mean Age (SD)	59.6 (10.1)	61.2 (12.0)
Age Category		
Less than 45	1,036 (5.9%)	219 (7.4%)
45-54	3,691 (21.1%)	571 (19.3%)
55-64	8,770 (50.1%)	1,200 (40.6%)
65-74	2,562 (14.6%)	516 (17.5%)
75 and above	1,455 (8.3%)	448 (15.2%)
Sex: Females	8,793 (50.2%)	1,537 (52.0%)
Insurance Type		
Commercial	11,628 (66.4%)	1,437 (48.6%)
Medicare	3,286 (18.8%)	800 (27.1%)
Medicaid	2,600 (14.8%)	717 (24.3%)
Year		
2016	7,715 (44.1%)	1,487 (50.3%)
2017	7,765 (44.3%)	1,195 (40.5%)
2018	2,034 (11.6%)	272 (9.2%)
Mean ECI (SD)	2.1 (1.9)	3.6 (2.7)
ECI Category		
Score: 0	3,422 (19.5%)	268 (9.1%)
Score: 1-2	8,211 (46.9%)	953 (32.3%)
Score: 3-4	4,098 (23.4%)	851 (28.8%)
Score: 5+	1,783 (10.2%)	882 (29.9%)

Comorbidities (*Data shown: N (% of total cohort)*	Primary THA	Revision THA
Hypertension		
Uncomplicated	9,444 (53.9%)	2,011 (68.1%)
Complicated	784 (4.5%)	318 (10.8%)
Obesity	3,202 (18.3%)	784 (26.5%)
Chronic Pulmonary Diseases, including Asthma	2,595 (14.8%)	782 (26.5%)
Depression	2,573 (14.7%)	813 (27.5%)
Cardiac arrythmias	2,502 (14.3%)	720 (24.4%)
Diabetes		
Uncomplicated	2,391 (13.7%)	615 (20.8%)
Complicated	1,149 (6.6%)	360 (12.2%)
Hypothyroidism	2,377 (13.6%)	552 (18.7%)

Rheumatoid arthritis / collagen vascular diseases	1,476 (8.4%)	421 (14.3%)
Valvular disease	1,041 (5.9%)	350 (11.8%)
Peripheral vascular disorders	1,007 (5.7%)	360 (12.2%)
Fluid and electrolyte disorders	994 (5.7%)	476 (16.1%)

ECI: Elixhauser Index. SD: Standard Deviation. THA = Total Hip Arthroplasty.

Table 2. Clinical characteristics of patients, by post-operative infection status

Data shown: N (% of total cohort), or if indicated: mean (SD)

	Primary THA			Revision THA		
Variables	**Deep SSI**	**Superficial SSI**	**No Infection**	**Deep SSI**	**Superficial SSI**	**No Infection**
All	53	117	17,344	251	136	2,567
Mean Age (SD)	56.6 (10.4)	58.2 (9.5)	59.6 (10.1)	61.3 (13.2)	59.1 (11.8)	61.3 (11.9)
Age Category						
Less than 45	5 (9.4%)	8 (6.8%)	1,023 (5.9%)	26 (10.4%)	13 (9.6%)	180 (7.0%)
45-54	16 (30.2%)	23 (19.7%)	3,652 (21.1%)	37 (14.7%)	26 (19.1%)	508 (19.8%)
55-64	24 (45.3%)	65 (55.6%)	8,681 (50.1%)	98 (39.0%)	64 (47.1%)	1,038 (40.4%)
65-74	4 (7.5%)	15 (12.8%)	2,543 (14.7%)	45 (17.9%)	21 (15.4%)	450 (17.5%)
75 and above	4 (7.5%)	6 (5.1%)	1,445 (8.3%)	45 (17.9%)	12 (8.8%)	391 (15.2%)
Sex: Female	26 (49.1%)	61 (52.1%)	8,706 (50.2%)	110 (43.8%)	75 (55.1%)	1,352 (52.7%)
Mean ECI (SD)	3.5 (2.7)	2.8 (2.0)	2.1 (1.8)	5.4 (3.1)	4.4 (3.2)	3.3 (2.5)
ECI Category						
Score: 0	3 (5.7%)	12 (10.3%)	3,407 (19.6%)	6 (2.4%)	7 (5.1%)	255 (9.9%)
Score: 1-2	22 (41.5%)	50 (42.7%)	8,139 (46.9%)	45 (17.9%)	40 (29.4%)	868 (33.8%)
Score: 3-4	16 (30.2%)	31 (26.5%)	4,051 (23.4%)	55 (21.9%)	32 (23.5%)	764 (29.8%)
Score: 5+	12 (22.6%)	24 (20.5%)	1,747 (10.1%)	145 (57.8%)	57 (41.9%)	680 (26.5%)

ECI: Elixhauser Index. SD: Standard Deviation. SSI = Surgical site infection. THA = Total Hip Arthroplasty.

Table 3: Key Comorbidities of Patients with primary or revision THA, based on post-operative infection status.

Data shown: N (% of total cohort)

	Primary THA			Revision THA		
Variables	**Deep SSI**	**Superficial SSI**	**No Infection**	**Deep SSI**	**Superficial SSI**	**No Infection**
Hypertension						
Uncomplicated	36 (67.9%)	76 (65.0%)	9,332 (53.8%)	208 (82.9%)	95 (69.9%)	1,708 (66.5%)
Complicated	4 (7.5%)	9 (7.7%)	771 (4.4%)	46 (18.3%)	13 (9.6%)	259 (10.1%)
Elix 23 Obesity	18 (34.0%)	29 (24.8%)	3,155 (18.2%)	97 (38.6%)	51 (37.5%)	636 (24.8%)
Elix 31 Depression	16 (30.2%)	25 (21.4%)	2,532 (14.6%)	101 (40.2%)	50 (36.8%)	662 (25.8%)
Diabetes						
Uncomplicated	15 (28.3%)	21 (17.9%)	2,355 (13.6%)	76 (30.3%)	31 (22.8%)	508 (19.8%)
Complicated	12 (22.6%)	16 (13.7%)	1,121 (6.5%)	56 (22.3%)	18 (13.2%)	286 (11.1%)
Cardiac arrhythmias	14 (26.4%)	18 (15.4%)	2,470 (14.2%)	87 (34.7%)	41 (30.1%)	592 (23.1%)
Chronic pulmonary disease, including Asthma	13 (24.5%)	22 (18.8%)	2,560 (14.8%)	95 (37.8%)	43 (31.6%)	644 (25.1%)
Rheumatoid arthritis / collagen vascular diseases	10 (18.9%)	13 (11.1%)	1,453 (8.4%)	47 (18.7%)	20 (14.7%)	354 (13.8%)
Renal failure	7 (13.2%)	9 (7.7%)	707 (4.1%)	42 (16.7%)	15 (11.0%)	219 (8.5%)
Valvular disease	6 (11.3%)	8 (6.8%)	1,027 (5.9%)	45 (17.9%)	19 (14.0%)	286 (11.1%)
Peripheral vascular disorders	6 (11.3%)	10 (8.5%)	991 (5.7%)	42 (16.7%)	22 (16.2%)	296 (11.5%)
Fluid and electrolyte disorders	6 (11.3%)	11 (9.4%)	977 (5.6%)	91 (36.3%)	29 (21.3%)	356 (13.9%)
Hypothyroidism	5 (9.4%)	26 (22.2%)	2,346 (13.5%)	54 (21.5%)	28 (20.6%)	470 (18.3%)
Congestive heart failure	4 (7.5%)	7 (6.0%)	612 (3.5%)	46 (18.3%)	15 (11.0%)	201 (7.8%)

SSI = Surgical site infection. THA = Total Hip Arthroplasty.

Figure 1. Hazard ratios of demographic and comorbid variables for superficial SSI following primary THA.

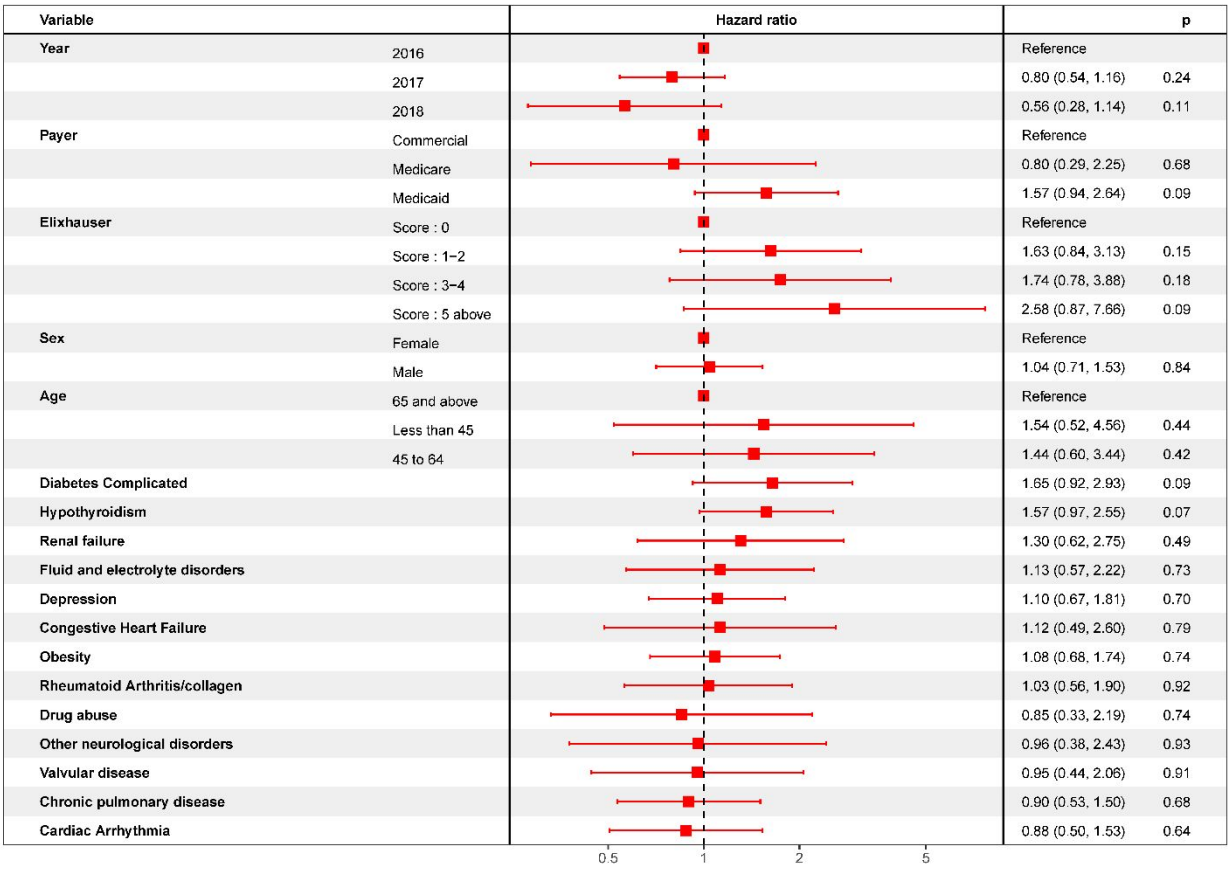

Figure 2. Hazard ratios of demographic and comorbid variables for deep SSI following primary THA.

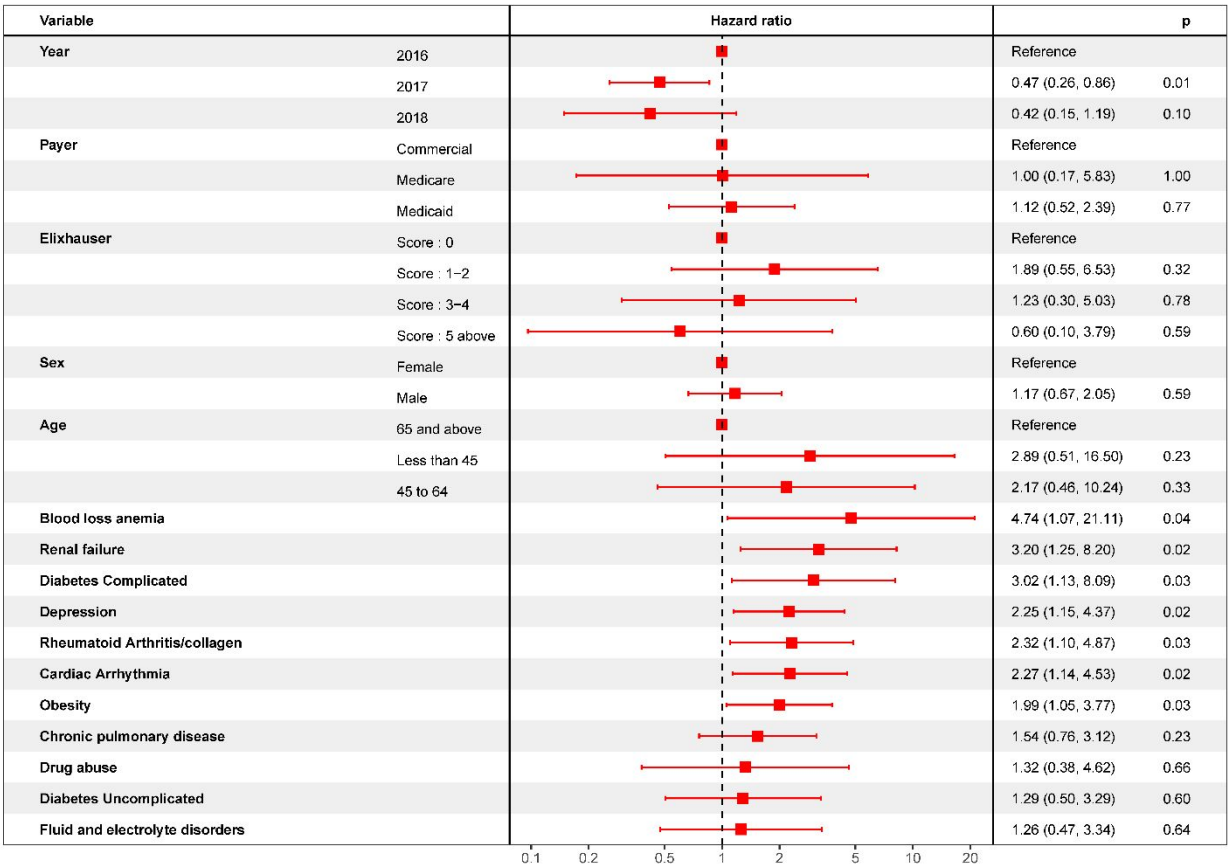

Figure 3. Hazard ratios of demographic and comorbid variables for superficial SSI following revision THA.

Variable		N	Hazard ratio	p
Year	2016	1487	Reference	
	2017	1195	1.20 (0.85, 1.70)	0.30
	2018	272	0.49 (0.21, 1.13)	0.10
Payer	Commercial	1437	Reference	
	Medicare	800	1.74 (0.61, 4.95)	0.30
	Medicaid	717	1.36 (0.87, 2.12)	0.17
Elixhauser	Score : 0	268	Reference	
	Score : 1−2	953	1.44 (0.62, 3.33)	0.40
	Score : 3−4	851	1.13 (0.44, 2.91)	0.80
	Score : 5 above	882	1.58 (0.54, 4.63)	0.40
Sex	Female	1537	Reference	
	Male	1417	0.88 (0.61, 1.26)	0.49
Age	65 and above	964	Reference	
	Less than 45	219	2.62 (0.90, 7.60)	0.08
	45 to 64	1771	2.40 (0.93, 6.19)	0.07
Coagulopathy		2954	1.86 (1.05, 3.27)	0.03
Obesity		2954	1.47 (1.01, 2.16)	0.05
Cardiac Arrhythmia		2954	1.24 (0.82, 1.86)	0.31
Depression		2954	1.18 (0.79, 1.77)	0.42
Diabetes Uncomplicated		2954	1.02 (0.60, 1.74)	0.93
Fluid and electrolyte disorders		2954	1.07 (0.67, 1.71)	0.77
Hypothyroidism		2954	1.08 (0.69, 1.69)	0.73
Chronic pulmonary disease		2954	0.99 (0.65, 1.50)	0.94
Hypertension Uncomplicated		2954	1.05 (0.72, 1.52)	0.81
Diabetes Complicated		2954	0.92 (0.49, 1.74)	0.79
Rheumatoid Arthritis/collagen		2954	0.83 (0.50, 1.36)	0.45

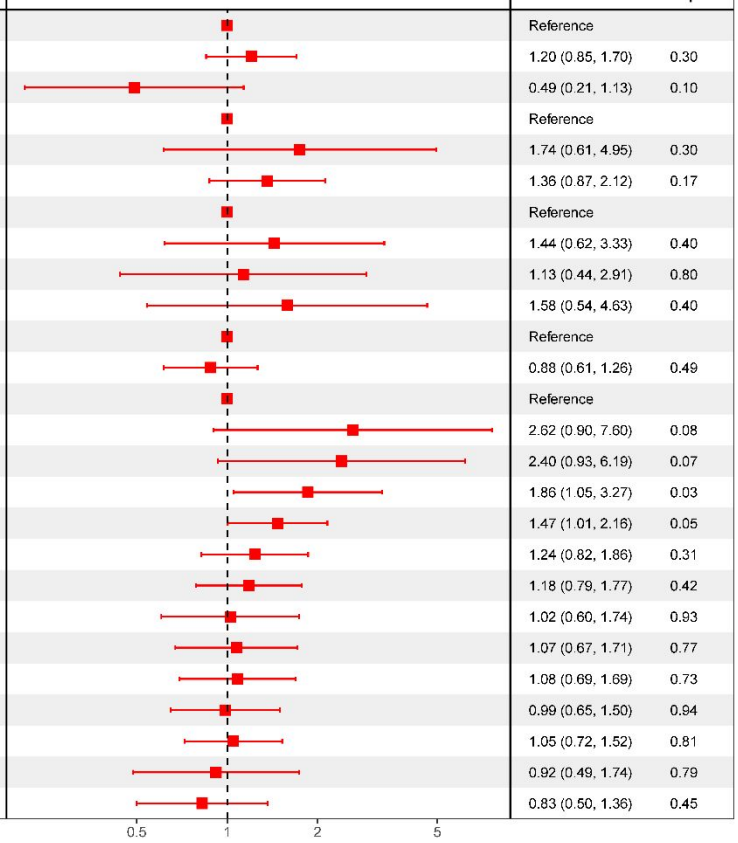

Figure 4. Hazard ratios of demographic and comorbid variables for deep SSI following revision THA.

Variable		N	Hazard ratio	p
Year	2016	1487	Reference	
	2017	1195	1.00 (0.77, 1.30)	0.989
	2018	272	0.79 (0.48, 1.30)	0.362
Payer	Commercial	1437	Reference	
	Medicare	800	0.82 (0.45, 1.50)	0.528
	Medicaid	717	0.91 (0.64, 1.29)	0.586
Elixhauser	Score : 0	268	Reference	
	Score : 1−2	953	1.97 (0.84, 4.66)	0.121
	Score : 3−4	851	2.23 (0.93, 5.37)	0.073
	Score : 5 above	882	3.76 (1.47, 9.62)	0.006
Sex	Female	1537	Reference	
	Male	1417	1.62 (1.24, 2.13)	<0.001
Age	65 and above	964	Reference	
	Less than 45	219	1.35 (0.73, 2.50)	0.332
	45 to 64	1771	0.79 (0.47, 1.32)	0.367
Fluid and electrolyte disorders		2954	1.84 (1.37, 2.49)	<0.001
Diabetes Complicated		2954	1.48 (1.07, 2.03)	0.016
Pulmonary circulation disorders		2954	1.67 (1.08, 2.58)	0.020
Malnutrition – Wasting Diseases		2954	1.45 (0.95, 2.24)	0.088
Obesity		2954	1.34 (1.01, 1.77)	0.040
Rheumatoid Arthritis/collagen		2954	1.21 (0.86, 1.69)	0.277
Depression		2954	1.20 (0.90, 1.61)	0.212
Deficiency anemia		2954	1.22 (0.87, 1.73)	0.251
Renal failure		2954	1.07 (0.75, 1.52)	0.721
Valvular disease		2954	1.04 (0.73, 1.48)	0.839
Hypothyroidism		2954	1.01 (0.74, 1.39)	0.944
Chronic pulmonary disease		2954	1.02 (0.76, 1.36)	0.920
Liver disease		2954	1.04 (0.68, 1.58)	0.870
Cardiac Arrhythmia		2954	0.99 (0.74, 1.32)	0.945

Table S1: Demographic and comorbid characteristics of patients treated with primary or revision total hip arthroplasty (pTHA or rTHA), with superficial infection (SI), deep infection (DI), or no infection (NI). pTHA: primary total hip arthroplasty; rTHA: revision total hip arthroplasty; SI: superficial infection; DI: deep infection, NI: no infection.

Variables	pTHA	pTHA DI	pTHA SI	pTHA NI	rTHA	rTHA DI	rTHA SI	rTHA NI
All	17,514	53	117	17,344	2,954	251	136	2,567
Mean Age (SD)	59.6 (10.1)	56.6 (10.4)	58.2 (9.5)	59.6 (10.1)	61.2 (12.0)	61.3 (13.2)	59.1 (11.8)	61.3 (11.9)
Age Category								
18-24	47 (0.3%)	0 (0.0%)	0 (0.0%)	47 (0.3%)	10 (0.3%)	1 (0.4%)	1 (0.7%)	8 (0.3%)
25-34	179 (1.0%)	0 (0.0%)	3 (2.6%)	176 (1.0%)	48 (1.6%)	8 (3.2%)	4 (2.9%)	36 (1.4%)
35-44	810 (4.6%)	5 (9.4%)	5 (4.3%)	800 (4.6%)	161 (5.5%)	17 (6.8%)	8 (5.9%)	136 (5.3%)
45-54	3,691 (21.1%)	16 (30.2%)	23 (19.7%)	3,652 (21.1%)	571 (19.3%)	37 (14.7%)	26 (19.1%)	508 (19.8%)
55-64	8,770 (50.1%)	24 (45.3%)	65 (55.6%)	8,681 (50.1%)	1,200 (40.6%)	98 (39.0%)	64 (47.1%)	1,038 (40.4%)
65-74	2,562 (14.6%)	4 (7.5%)	15 (12.8%)	2,543 (14.7%)	516 (17.5%)	45 (17.9%)	21 (15.4%)	450 (17.5%)
75 and above	1,455 (8.3%)	4 (7.5%)	6 (5.1%)	1,445 (8.3%)	448 (15.2%)	45 (17.9%)	12 (8.8%)	391 (15.2%)
Sex: Female	8,793 (50.2%)	26 (49.1%)	61 (52.1%)	8,706 (50.2%)	1,537 (52.0%)	110 (43.8%)	75 (55.1%)	1,352 (52.7%)
Insurance Type								
Commercial	11,628 (66.4%)	34 (64.2%)	73 (62.4%)	11,521 (66.4%)	1,437 (48.6%)	99 (39.4%)	64 (47.1%)	1,274 (49.6%)
Medicaid	2,600 (14.8%)	13 (24.5%)	30 (25.6%)	2,557 (14.7%)	717 (24.3%)	83 (33.1%)	44 (32.4%)	590 (23.0%)
Year								
2016	7,715 (44.1%)	33 (62.3%)	60 (51.3%)	7,622 (43.9%)	1,487 (50.3%)	129 (51.4%)	66 (48.5%)	1,292 (50.3%)
2017	7,765 (44.3%)	16 (30.2%)	48 (41.0%)	7,701 (44.4%)	1,195 (40.5%)	104 (41.4%)	64 (47.1%)	1,027 (40.0%)
2018	2,034 (11.6%)	4 (7.5%)	9 (7.7%)	2,021 (11.7%)	272 (9.2%)	18 (7.2%)	6 (4.4%)	248 (9.7%)
Mean ECI (SD)	2.1 (1.9)	3.5 (2.7)	2.8 (2.0)	2.1 (1.8)	3.6 (2.7)	5.4 (3.1)	4.4 (3.2)	3.3 (2.5)
ECI Category								
Score: 0	3,422 (19.5%)	3 (5.7%)	12 (10.3%)	3,407 (19.6%)	268 (9.1%)	6 (2.4%)	7 (5.1%)	255 (9.9%)
Score: 1-2	8,211 (46.9%)	22 (41.5%)	50 (42.7%)	8,139 (46.9%)	953 (32.3%)	45 (17.9%)	40 (29.4%)	868 (33.8%)
Score: 3-4	4,098 (23.4%)	16 (30.2%)	31 (26.5%)	4,051 (23.4%)	851 (28.8%)	55 (21.9%)	32 (23.5%)	764 (29.8%)
Score: 5+	1,783 (10.2%)	12 (22.6%)	24 (20.5%)	1,747 (10.1%)	882 (29.9%)	145 (57.8%)	57 (41.9%)	680 (26.5%)
Comorbidities								
Elix 01 Congestive heart failure	623 (3.6%)	4 (7.5%)	7 (6.0%)	612 (3.5%)	262 (8.9%)	46 (18.3%)	15 (11.0%)	201 (7.8%)
Elix 02 Cardiac arrhythmias	2,502 (14.3%)	14 (26.4%)	18 (15.4%)	2,470 (14.2%)	720 (24.4%)	87 (34.7%)	41 (30.1%)	592 (23.1%)
Elix 03 Valvular disease	1,041 (5.9%)	6 (11.3%)	8 (6.8%)	1,027 (5.9%)	350 (11.8%)	45 (17.9%)	19 (14.0%)	286 (11.1%)
Elix 04 Pulmonary circulation disorders	207 (1.2%)	2 (3.8%)	2 (1.7%)	203 (1.2%)	116 (3.9%)	26 (10.4%)	7 (5.1%)	83 (3.2%)
Elix 05 Peripheral vascular disorders	1,007 (5.7%)	6 (11.3%)	10 (8.5%)	991 (5.7%)	360 (12.2%)	42 (16.7%)	22 (16.2%)	296 (11.5%)

Elix 06 Hypertension, uncomplicated	9,444 (53.9%)	36 (67.9%)	76 (65.0%)	9,332 (53.8%)	2,011 (68.1%)	208 (82.9%)	95 (69.9%)	1,708 (66.5%)
Elix 07 Hypertension, complicated	784 (4.5%)	4 (7.5%)	9 (7.7%)	771 (4.4%)	318 (10.8%)	46 (18.3%)	13 (9.6%)	259 (10.1%)
Elix 08 Paralysis	44 (0.3%)	0 (0.0%)	0 (0.0%)	44 (0.3%)	23 (0.8%)	2 (0.8%)	2 (1.5%)	19 (0.7%)
Elix 09 Other neurological disorders	507 (2.9%)	1 (1.9%)	5 (4.3%)	501 (2.9%)	223 (7.5%)	34 (13.5%)	17 (12.5%)	172 (6.7%)
Elix 10 Chronic pulmonary disease	2,595 (14.8%)	13 (24.5%)	22 (18.8%)	2,560 (14.8%)	782 (26.5%)	95 (37.8%)	43 (31.6%)	644 (25.1%)
Elix 11 Diabetes, uncomplicated	2,391 (13.7%)	15 (28.3%)	21 (17.9%)	2,355 (13.6%)	615 (20.8%)	76 (30.3%)	31 (22.8%)	508 (19.8%)
Elix 12 Diabetes, complicated	1,149 (6.6%)	12 (22.6%)	16 (13.7%)	1,121 (6.5%)	360 (12.2%)	56 (22.3%)	18 (13.2%)	286 (11.1%)
Elix 13 Hypothyroidism	2,377 (13.6%)	5 (9.4%)	26 (22.2%)	2,346 (13.5%)	552 (18.7%)	54 (21.5%)	28 (20.6%)	470 (18.3%)
Elix 14 Renal failure	723 (4.1%)	7 (13.2%)	9 (7.7%)	707 (4.1%)	276 (9.3%)	42 (16.7%)	15 (11.0%)	219 (8.5%)
Elix 15 Liver disease	740 (4.2%)	3 (5.7%)	6 (5.1%)	731 (4.2%)	195 (6.6%)	26 (10.4%)	8 (5.9%)	161 (6.3%)
Elix 16 Peptic ulcer disease excluding bleeding	140 (0.8%)	3 (5.7%)	0 (0.0%)	137 (0.8%)	57 (1.9%)	9 (3.6%)	5 (3.7%)	43 (1.7%)
Elix 17 AIDS/HIV	82 (0.5%)	0 (0.0%)	2 (1.7%)	80 (0.5%)	28 (0.9%)	4 (1.6%)	2 (1.5%)	22 (0.9%)
Elix 18 Lymphoma	98 (0.6%)	1 (1.9%)	1 (0.9%)	96 (0.6%)	42 (1.4%)	5 (2.0%)	2 (1.5%)	35 (1.4%)
Elix 19 Metastatic cancer	116 (0.7%)	0 (0.0%)	0 (0.0%)	116 (0.7%)	35 (1.2%)	5 (2.0%)	2 (1.5%)	28 (1.1%)
Elix 20 Solid tumor without metastasis	1,013 (5.8%)	3 (5.7%)	6 (5.1%)	1,004 (5.8%)	207 (7.0%)	24 (9.6%)	13 (9.6%)	170 (6.6%)
Elix 21 Rheumatoid arthritis / collagen vascular diseases	1,476 (8.4%)	10 (18.9%)	13 (11.1%)	1,453 (8.4%)	421 (14.3%)	47 (18.7%)	20 (14.7%)	354 (13.8%)
Elix 22 Coagulopathy	555 (3.2%)	3 (5.7%)	5 (4.3%)	547 (3.2%)	171 (5.8%)	30 (12.0%)	15 (11.0%)	126 (4.9%)
Elix 23 Obesity	3,202 (18.3%)	18 (34.0%)	29 (24.8%)	3,155 (18.2%)	784 (26.5%)	97 (38.6%)	51 (37.5%)	636 (24.8%)
Elix 24 Weight loss	281 (1.6%)	3 (5.7%)	1 (0.9%)	277 (1.6%)	128 (4.3%)	27 (10.8%)	5 (3.7%)	96 (3.7%)
Elix 25 Fluid and electrolyte disorders	994 (5.7%)	6 (11.3%)	11 (9.4%)	977 (5.6%)	476 (16.1%)	91 (36.3%)	29 (21.3%)	356 (13.9%)
Elix 26 Blood loss anemia	138 (0.8%)	2 (3.8%)	2 (1.7%)	134 (0.8%)	86 (2.9%)	14 (5.6%)	2 (1.5%)	70 (2.7%)
Elix 27 Deficiency anemia	654 (3.7%)	2 (3.8%)	8 (6.8%)	644 (3.7%)	285 (9.6%)	45 (17.9%)	17 (12.5%)	223 (8.7%)
Elix 28 Alcohol abuse	418 (2.4%)	2 (3.8%)	1 (0.9%)	415 (2.4%)	155 (5.2%)	26 (10.4%)	10 (7.4%)	119 (4.6%)

Elix 29 Drug abuse	503 (2.9%)	3 (5.7%)	5 (4.3%)	495 (2.9%)	242 (8.2%)	37 (14.7%)	21 (15.4%)	184 (7.2%)
Elix 30 Psychoses	136 (0.8%)	0 (0.0%)	2 (1.7%)	134 (0.8%)	65 (2.2%)	14 (5.6%)	7 (5.1%)	44 (1.7%)
Elix 31 Depression	2,573 (14.7%)	16 (30.2%)	25 (21.4%)	2,532 (14.6%)	813 (27.5%)	101 (40.2%)	50 (36.8%)	662 (25.8%)

Figure S1: Cumulative hazard for superficial infection following primary THA. At 6 months post-THA, the cumulative hazard for superficial infection reached 0.67% (95%CI: 0.55%-0.79%)

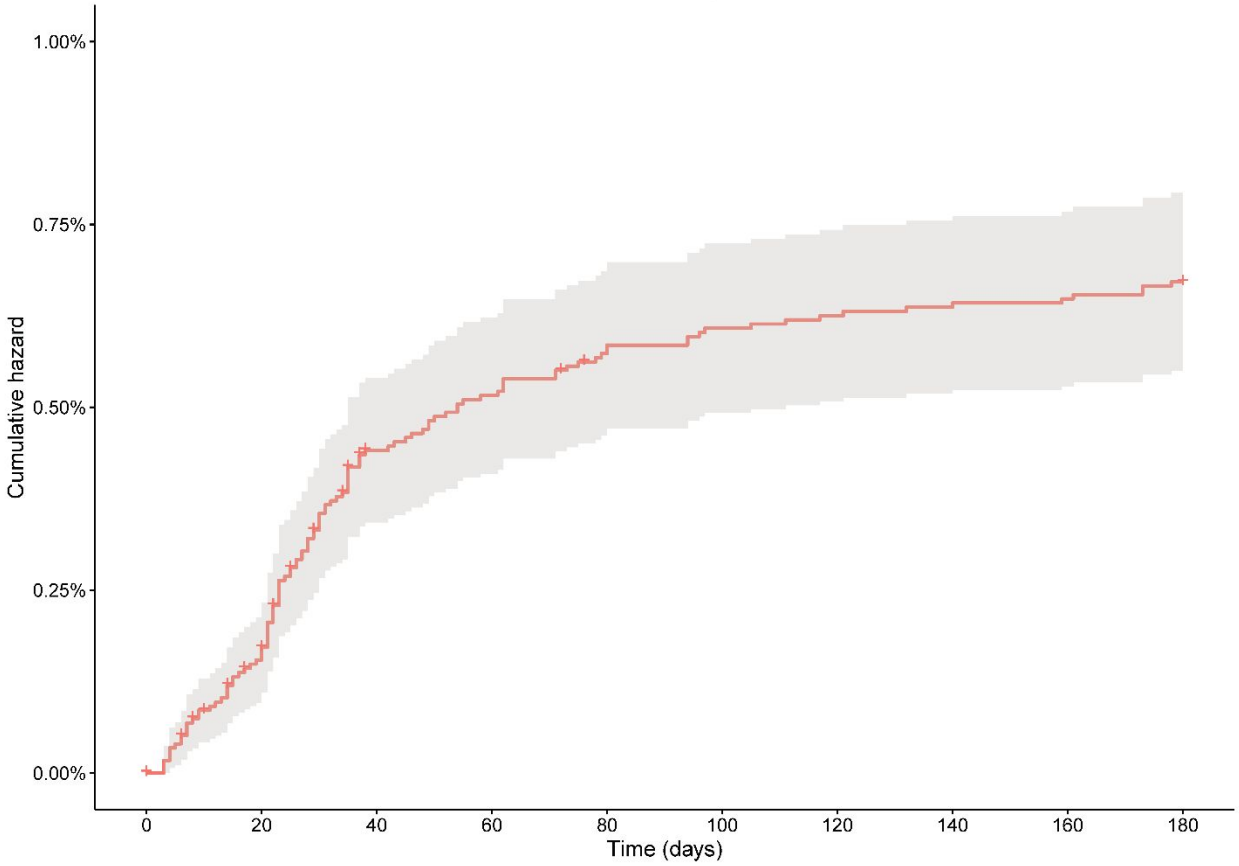

Figure S2: Cumulative hazard for deep infection following primary THA. At 6 months post-THA, the cumulative hazard for deep infection reached 0.30% (95%CI: 0.22%-0.39%)

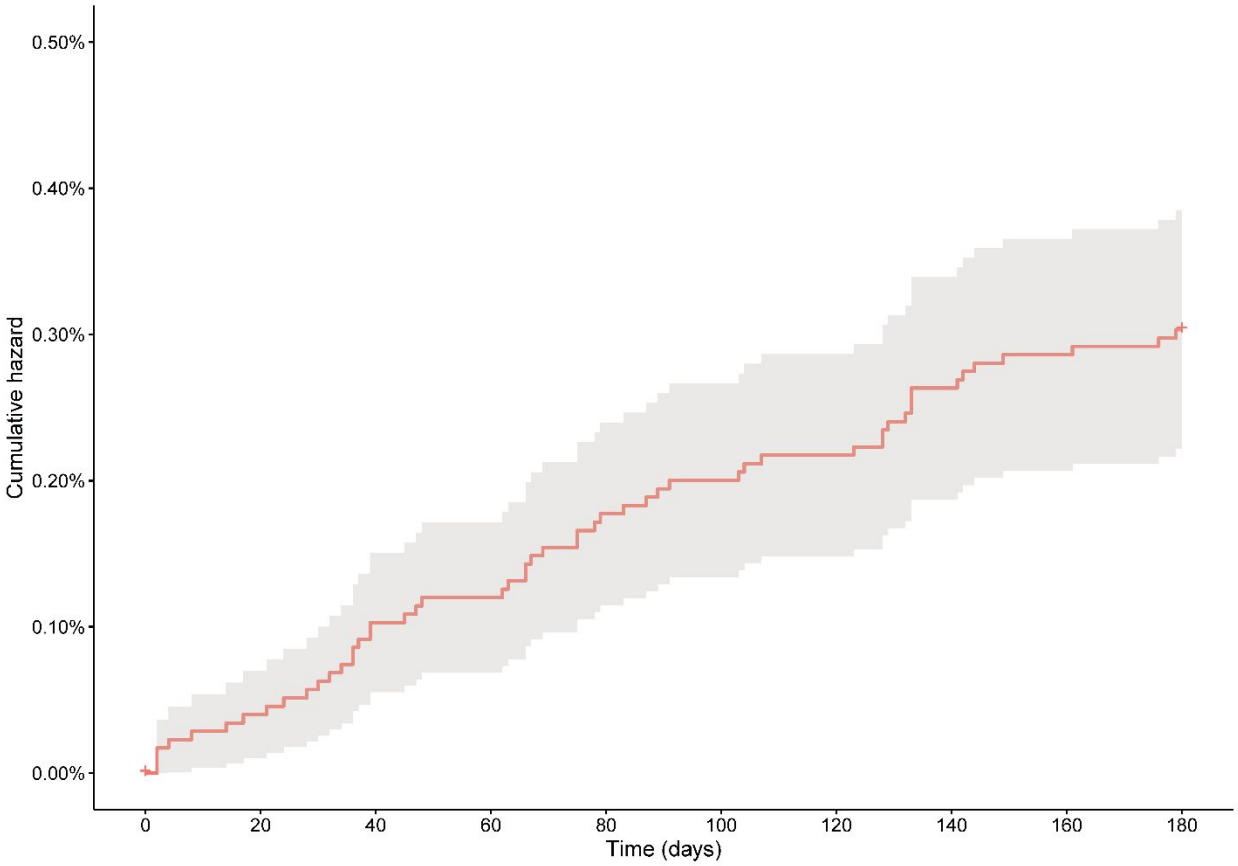

Figure S3: Cumulative hazard for superficial infection following revision THA. At 6 months post-THA, the cumulative hazard for superficial infection reached 4.8% (95%CI: 4.0%-5.6%)

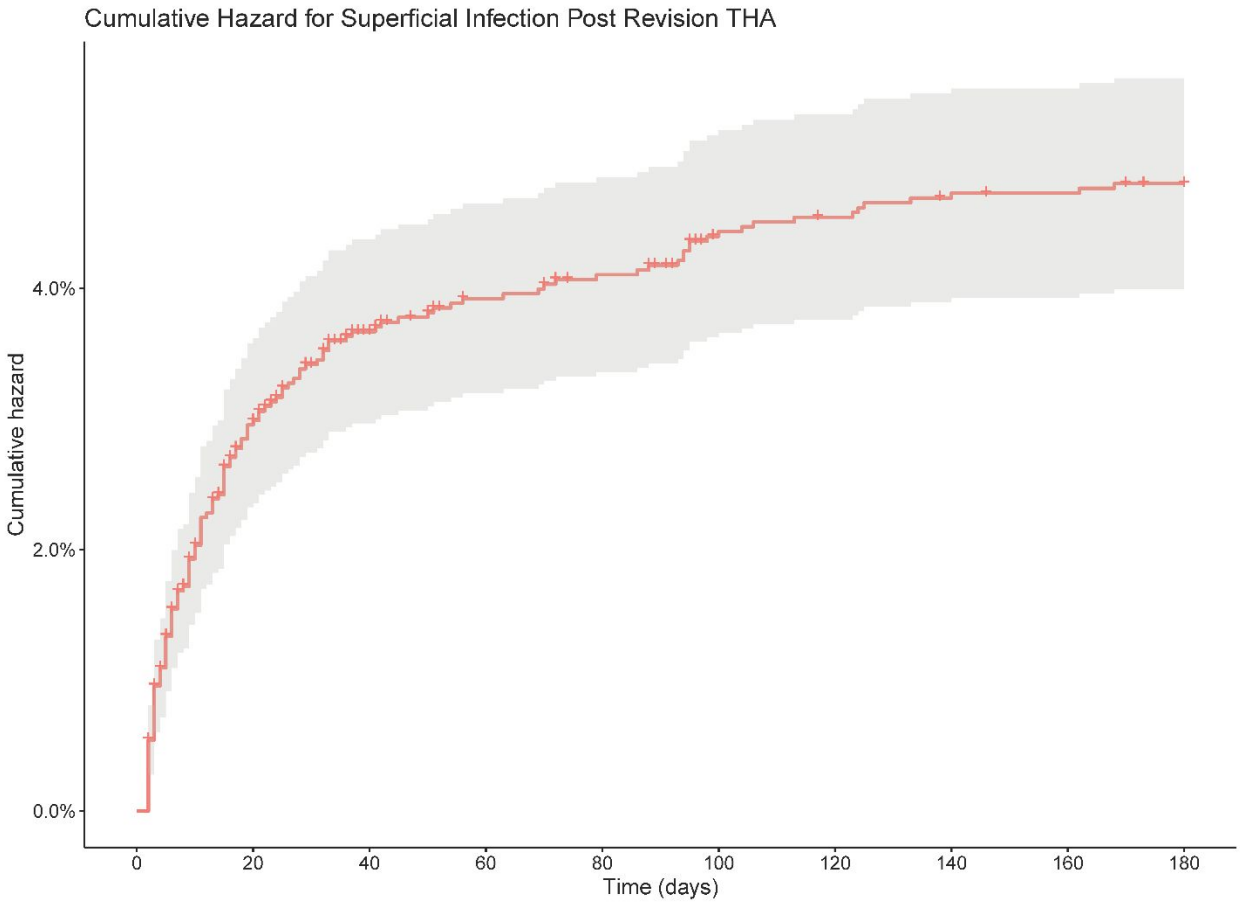

Figure S4: Cumulative Hazard for deep infection following revision THA, in all revision cases or revision cases excluding deep infections. At 6 months post-THA, the cumulative hazard for new or continued diagnoses of deep infection reached 8.9% (95%CI: 7.8%-10.0%) of all revision cases, and 6.0% (95%CI: 5.1%-6.9%) of all revision cases excluding prior infections.

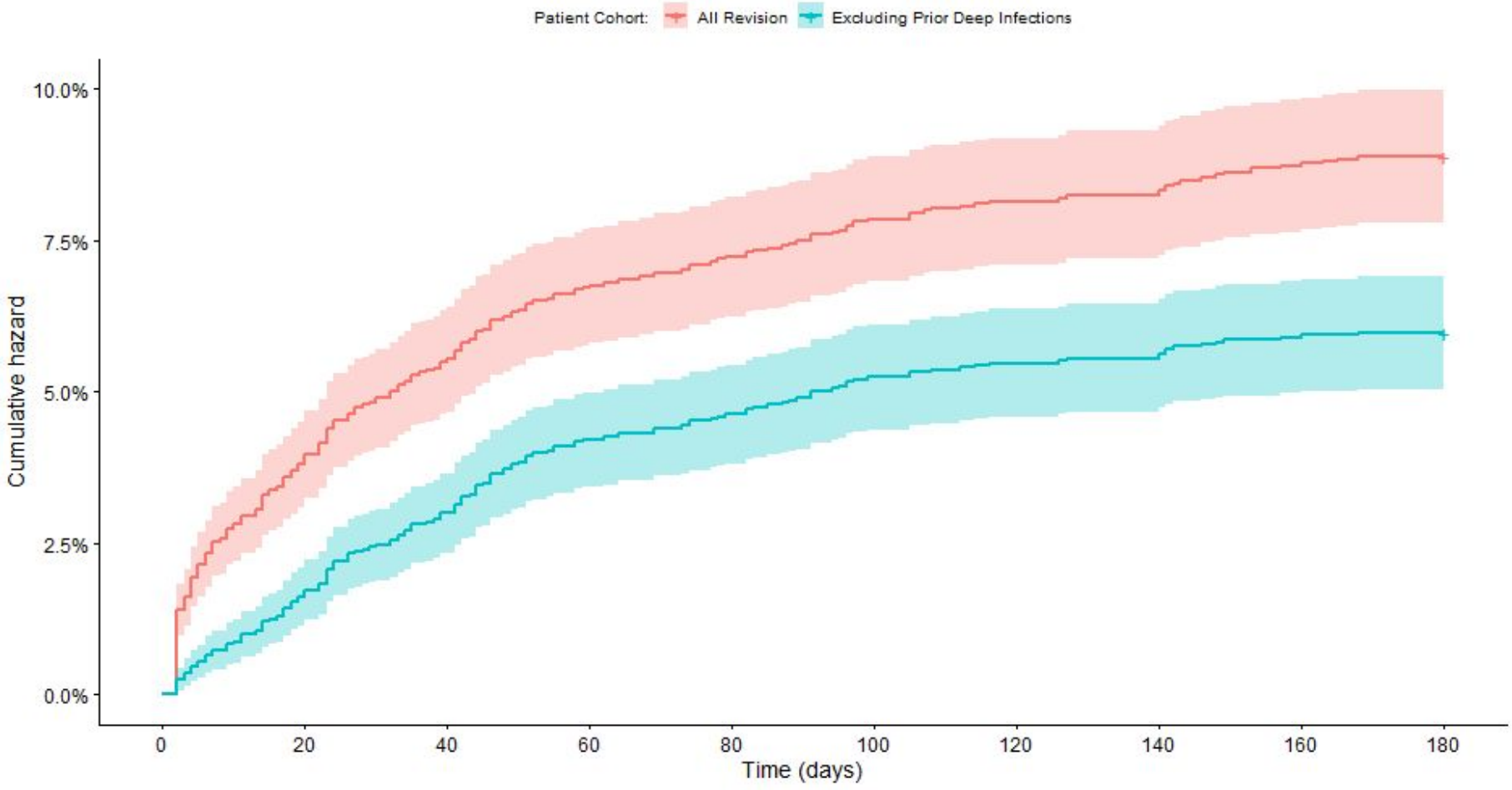

Figure S5: Hazard ratios of demographic and comorbid variables for deep SSI following revision THA, in patients without deep infection prior to, and at time of, revision.

Variable		N	Hazard ratio	p
Year	2016	1357	Reference	
	2017	1124	0.99 (0.72, 1.38)	0.962
	2018	258	0.88 (0.49, 1.59)	0.682
Payer	Commercial	1342	Reference	
	Medicare	754	0.82 (0.39, 1.75)	0.612
	Medicaid	643	0.91 (0.58, 1.41)	0.666
Elixhauser	Score : 0	261	Reference	
	Score : 1−2	911	1.22 (0.45, 3.34)	0.697
	Score : 3−4	797	1.22 (0.42, 3.56)	0.711
	Score : 5 above	770	1.70 (0.54, 5.31)	0.363
Sex	Female	1452	Reference	
	Male	1287	1.70 (1.22, 2.38)	0.002
Age	65 and above	905	Reference	
	Less than 45	194	1.12 (0.50, 2.50)	0.787
	45 to 64	1640	0.76 (0.40, 1.47)	0.415
Pulmonary circulation disorders		2739	2.05 (1.20, 3.51)	0.009
Depression		2739	1.84 (1.28, 2.65)	0.001
Fluid and electrolyte disorders		2739	1.63 (1.10, 2.40)	0.014
Hypertension		2739	1.58 (0.95, 2.63)	0.080
Obesity		2739	1.36 (0.96, 1.93)	0.084
Rheumatoid Arthritis/collagen		2739	1.26 (0.82, 1.94)	0.285
Coagulopathy		2739	1.22 (0.71, 2.11)	0.465
Diabetes Complicated		2739	1.20 (0.79, 1.84)	0.395
Malnutrition – Wasting Diseases		2739	1.07 (0.56, 2.05)	0.837