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An epidemiological analysis of revision aetiologies in total hip arthroplasty at a single high-volume centre

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Aims

Advances in surgical technique and implant design may influence the incidence and mechanism of failure resulting in revision total hip arthroplasty (rTHA). The purpose of the current study was to characterize aetiologies requiring rTHA, and to determine whether temporal changes existed in these aetiologies over a ten-year period.

Methods

All rTHAs performed at a single institution from 2009 to 2019 were identified. Demographic information and mode of implant failure was obtained for all patients. Data for rTHA were stratified into two time periods to assess for temporal changes: 2009 to 2013, and 2014 to 2019. Operative reports, radiological imaging, and current procedural terminology (CPT) codes were cross-checked to ensure the accurate classification of revision aetiology for each patient.

Results

In all, 2,924 patients with a mean age of 64.6 years (17 to 96) were identified. There were 1,563 (53.5%) female patients, and the majority of patients were Caucasian (n = 2,362, 80.8%). The three most frequent rTHA aetiologies were infection (27.2%), aseptic loosening (25.2%), and wear (15.2%). The frequency of rTHA for adverse local tissue reaction (ALTR) was significantly greater from 2014 to 2019 (4.7% vs 10.0%; p < 0.001), while the frequency of aseptic loosening was significantly greater from 2009 to 2013 (28.6% vs 21.9%; p < 0.001).

Conclusion

Periprosthetic joint infection was the most common cause for rTHA in the current cohort of patients. Complications associated with ALTR necessitating rTHA was more frequent between 2014 to 2019, while aseptic loosening necessitating rTHA was significantly more frequent between 2009 to 2013. Optimizing protocols for prevention and management of infection and ALTR after THA may help to avoid additional financial burden to institutions and healthcare systems.

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Introduction

While total hip arthroplasty (THA) remains one of the most successful surgical procedures to date, increasing demand for THA in the USA will lead to a subsequent rise in the number of annual revision arthroplasty procedures.[1-3] As alternative payment models become more widely adopted, substantial costs associated with THA that result in the need for a revision procedure will impose financial burden on the healthcare system. Understanding the epidemiology of revision THA aetiology and how aetiologies have changed over recent years may benefit insurers and healthcare institutions by better anticipating costs and appropriating resources. Additionally, epidemiological studies can benefit surgeons and patient outcomes by providing a perspective on current trends in revision THA and how to better optimize protocols and management strategies. Furthermore, as THA revisions that require longer surgical times are often not compensated at a level commensurate with the level of complexity,[4-8] understanding the incidence and trends in revision THA may be

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a step towards challenging this case-compensation/relative value unit (RVU) mismatch.

Well-documented causes necessitating THA revision include wound dehiscence, mechanical (aseptic) loosening, bearing surface wear, dislocation/instability, infection, adverse local tissue reaction, and implant failure.[9-14] Although previous studies have sought to determine causes for revision THA, these reflect statistics from national database studies which have inherent limitations, namely that inclusion and exclusion criteria are not known, and surgical techniques and patient populations are heterogeneous.[3,9] Furthermore, national databases are subject to CPT coding inaccuracies, where the indication and definition of revision is unclear or misleading, resulting in inflated or inaccurate data. Quality data from a high-volume practice is therefore necessary to better understand the aetiology of revision THA and may have implications in resource allocation for hospital systems with similar models. Furthermore, this knowledge may contribute to how surgeons determine the balance of their surgical volume, as revision THA has evolved into a complex balance of maximizing patient outcomes and minimizing costs.

Given the potential clinical and financial utility of epidemiological data in the current healthcare environment, the purpose of the current study was to characterize aetiologies that required revision THA, and to determine whether temporal changes existed in these aetiologies over a ten-year period. We hypothesized that complications requiring revision THA, when temporally stratified, would show decreased complications in the latter half of the study period due to improvements in implant design, operative planning, patient education, and postoperative therapy and medical management.

Methods

Identification of study population. Institutional review board approval was obtained prior to performing a retrospective review of all patients who underwent revision THA between 2009 and 2019. Patient cases were queried from a large institutional arthroplasty registry and extracted based on matched CPT codes for hips (27090, 27091, 27132, 27134, 27137, 27138). Inclusion criteria were patients who had received a previous THA and underwent subsequent revision surgery. Patients included in the study were undergoing at minimum their first revision procedure, while more complex patients presenting to our tertiary referral centre may have had multiple procedures prior to presentation at our institution. A total of seven fellowship-trained arthroplasty surgeons contributed to this registry. During the course of the study, Surgeon 1 was in practice for 13 to 23 years, Surgeon 2 was in practice for 7 to 17 years, Surgeon 3 was in practice for 4 to 14 years, Surgeon 4 was in practice for 3 to 13 years, Surgeon 5 was in practice for 1 to 6 years, Surgeon 6 was in practice for 29 to 39 years, and Surgeon 7 was in practice for 6 to 16 years. The initial query identified a total of 2,953 THA patients over the study period.

Table I. Raw and final data composition of aetiologies of revision hip arthroplasty.

Aetiology	Raw data	Final data
Dislocation, n (%)	361 (12.2)	410 (14.0)
Failed hemiarthroplasty converted to THA, n (%)	5 (0.2)	31 (1.1)
Fracture, n (%)	188 (6.4)	196 (6.7)
Infection, n (%)	775 (26.2)	794 (27.2)
Local tissue reaction, n (%)	14 (0.5)	216 (7.4)
Aseptic loosening, n (%)	562 (19.0)	738 (25.2)
Malpositioning-iliopsoas tendinitis with component revision, n (%)	2 (0.1)	27 (0.9)
Mechanical failure, n (%)	660 (22.4)	53 (1.8)
Miscellaneous, n (%)	0 (0.0)	10 (0.3)
Wear, n (%)	381 (12.9)	443 (15.2)
Wound dehiscence, n (%)	5 (0.2)	6 (0.2)
Total	2,953	2,924

THA, total hip arthroplasty.

Patients' electronic medical records, including details of the operative report and radiological imaging, were reviewed and cross-checked to ensure diagnostic information was accurately documented and coding errors avoided in relation to the aetiology necessitating revision. Patient information that was pooled and repeated due to clerical error was also removed from the study to ensure accurate representation of the patient population. Modes of failure including "Osteoarthritis", "Avascular Necrosis", and "Childhood Hip Problem" as well as repeated patients due to clerical error were among the 29 diagnoses on initial review that were deemed false causes of revision hip arthroplasty, and thus were removed from further analysis. Further analysis was performed to ensure the CPT codes and diagnosis in the patients' charts represented the true aetiology of revision. Diagnoses (mode of failure) were then systematically analyzed further by two fellowship-trained orthopaedic surgeons, an adult reconstruction attending physician (BRL) and adult reconstruction fellow (MBO), if discrepancies were encountered or the primary revision diagnosis was unclear. The breakdown of overall aetiologies of revision from the original dataset and the final dataset after further vetting of the patients' medical records is shown in Table I.

Data collection. Demographic information including date of surgery, age, race, and mode of implant failure was obtained for all patients (Tables II and III). Data for revision hip arthroplasty procedures were stratified into two time periods based on date range: 2009 to 2013, and 2014 to 2019. This stratification was based on the timing of faculty volumes as well as stage in each of the seven surgeons' careers. The split was at a critical time in lower limb arthroplasty in the USA when certain bearings were changing from metal-on-metal to ceramic-on-polyethylene,

Table II. Hip demographics.

Ethnicity	2009 to 2013	2014 to 2019
White, n (%)	1,128 (77.4)	1,234 (84.1)
Black or African-American, n (%)	128 (8.8)	121 (8.2)
Asian, n (%)	9 (0.6)	12 (0.8)
American Indian, n (%)	2 (0.1)	2 (0.1)
Hispanic, n (%)	30 (2.1)	26 (1.8)
Other/Did not indicate, n (%)	160 (11.0)	72 (4.9)
Sex, n (%)		
Male	647 (44.4)	714 (48.7)
Female	810 (55.6)	753 (51.3)
Mean age, yrs (range)	63.9 (17 to 96)	65.2 (20 to 92)

femoral head sizes were changing (increase in femoral head diameters from 28/32 to 36/40) and new diagnoses were becoming more prevalent, including trunnionosis. The diagnoses (mode of failure) for hips requiring revision included dislocation, failed hemiarthroplasty converted to THA, fracture, infection, local tissue reaction, loosening, malpositioning-iliopsoas tendinitis, mechanical failure, wear, and wound dehiscence.

Statistical analysis. Revision aetiology frequency was quantified for THA independently and presented as frequencies with percentages. Following temporal stratification of THA patients, revision aetiology frequencies were compared using chi-squared analysis of associations. If the total frequency of events for a revision aetiology was less than five, Fisher's exact test was performed. Continuous data were compared using independent-samples *t*-tests. All analyses were performed using Stata v.16.1 (Stata Corp, College Station, Texas, USA). Statistical significance was set at $p < 0.05$.

Results

Revision total hip arthroplasty: epidemiology. A total of 2,924 patients undergoing revision THA between 2009 to 2019 were identified with a mean age of 64.6 years (17 to 96). A total of 1,563 (53.5%) patients were female, and the majority of patients were Caucasian (n = 2,362, 80.8%). Prior to vetting of the initial raw dataset from the internal database, infection (n = 775; 26.2%), mechanical failure (n = 660; 22.4%), and aseptic loosening (n = 562; 19.0%) were the three most common etiologies that ultimately resulted in a revision hip arthroplasty (Table I). Substantial differences were seen after a secondary evaluation of the data. The vetting process of each patient revealed that the initial dataset underreported dislocation (12.2% vs 14.0%), failed hemiarthroplasty converted to THA (0.2% vs 1.1%), fracture (6.4% vs 6.7%), infection (26.2% vs 27.2%), local tissue reaction (0.5% vs 7.4%), aseptic loosening (19.0% vs 25.2%), malpositioning-iliopsoas tendinitis with component revision (0.1% vs 0.9%), and wear (12.9% vs 15.2%). Comparatively, the mechanical failure group was significantly overrepresented from the initial dataset prior to this intensive secondary analysis, compared to after the review process (22.4% vs 1.8%). This mechanical failure group was the seventh most frequent aetiology of revision in the finalized dataset. The three most frequent revision aetiologies for these patients in the finalized dataset was infection (n = 794; 27.2%), followed by aseptic loosening (n = 738; 25.2%), and wear (n = 443; 15.2%). The number and percentages of all the finalized data revision aetiologies are listed in Table IV.

Table III. Hip revision aetiologies and demographics.

Dislocation	Mean age, yrs (range)	Sex (M: F)	Incidence, n
2009 to 2013	65.6 (17 to 96)	77:138	215
2014 to 2019	67.6 (37 to 90)	68:127	195
Failed hemiarthroplasty converted to THA			
2009 to 2013	65.4 (37 to 91)	4:9	13
2014 to 2019	64.6 (37 to 84)	6:12	18
Fracture			
2009 to 2013	67.8 (29 to 95)	28:62	90
2014 to 2019	67.5 (25 to 89)	35:71	106
Infection			
2009 to 2013	61.9 (22 to 91)	207:187	394
2014 to 2019	62.5 (20 to 92)	224:176	400
Local tissue reaction			
2009 to 2013	59.9 (30 to 88)	32:37	69
2014 to 2019	62.4 (24 to 83)	83:64	147
Aseptic loosening			
2009 to 2013	65.4 (24 to 95)	178:239	417
2014 to 2019	66.7 (32 to 91)	153:168	321
Malpositioning-iliopsoas tendinitis with component revision			
2009 to 2013	57.3 (36 to 79)	7:5	12
2014 to 2019	60.3 (39 to 75)	5:10	15
Mechanical failure			
2009 to 2013	62.6 (49 to 84)	10:17	27
2014 to 2019	61.2 (32 to 81)	12:14	26
Miscellaneous			
2009 to 2013	55.5 (55 to 56)	0:2	2
2014 to 2019	65.4 (52 to 75)	3:5	8
Wear			
2009 to 2013	63.4 (29 to 95)	104:111	215
2014 to 2019	67.3 (38 to 91)	124:104	228
Wound dehiscence			
2009 to 2013	65.7 (65 to 67)	0:3	3
2014 to 2019	71.3 (67 to 76)	1:2	3

THA, total hip arthroplasty.

Revision total hip arthroplasty aetiology: temporal trends. The ten-year study period was stratified into early (2009 to 2013) and late (2014 to 2019) time periods. A total of 1,457 patients underwent revision THA between 2009 to 2013, while a total of 1,467 underwent revision THA between 2014 to 2019. Following stratification, no statistically significant differences were observed in age, sex, or race. Chi-squared analysis of association demonstrated that the frequency of revisions for local tissue reaction resulting in osteolysis was significantly greater in

Table IV. Temporal stratification and percentage breakdown of all hip revisions.

Aetiology	2009 to 2013 THA, n (%)	2014 to 2019 THA, n (%)	Overall THA, n (%)	p-value
Dislocation	215 (14.8)	195 (13.3)	410 (14.0)	0.25
Failed hemiarthroplasty converted to THA	13 (0.9)	18 (1.2)	31 (1.1)	0.38
Fracture	90 (6.2)	106 (7.2)	196 (6.7)	0.26
Infection	394 (27.0)	400 (27.3)	794 (27.2)	0.89
Local tissue reaction	69 (4.7)	147 (10.0)	216 (7.4)	< 0.001
Aseptic loosening	417 (28.6)	321 (21.9)	738 (25.2)	< 0.001
Malpositioning-iliopsoas tendinitis with component revision	12 (0.8)	15 (1.0)	27 (0.9)	0.57
Mechanical failure	27 (1.9)	26 (1.8)	53 (1.8)	0.89
Miscellaneous	2 (0.1)	8 (0.5)	10 (0.3)	0.11
Wear	215 (14.8)	228 (15.5)	443 (15.2)	0.55
Wound dehiscence	3 (0.2)	3 (0.2)	6 (0.2)	0.99
Total	1,457	1,467	2,924	N/A

N/A, not applicable; THA, total hip arthroplasty.

the 2014 to 2019 time period (4.7% vs 10.0%; p < 0.001), while the frequency of aseptic loosening was significantly greater in the 2009 to 2013 time period (28.6% vs 21.9%; p < 0.001). No statistically significant differences were found in the frequency of dislocation/instability (14.8% vs 13.3%; p = 0.25), conversion to THA from hemiarthroplasty (0.9% vs 1.2%; p = 0.38), periprosthetic fracture (6.2% vs 7.2%; p = 0.26), periprosthetic joint infection (PJI) (27.0% vs 27.3%; p = 0.89), acetabular component revision secondary to overhang and iliopsoas tendinitis (0.8% vs 1.0%; p = 0.57), mechanical failure (1.9% vs 1.8%; p = 0.89), miscellaneous causes (0.1% vs 0.5%; p = 0.11), wear and osteolysis (14.8% vs 15.5%; p = 0.55), and wound dehiscence (0.2% vs 0.2%; p = 0.99).

Discussion

This study analyzed 2,924 patients undergoing revision THA from 2009 to 2019 to understand the aetiology in revision procedures at our institution. The major findings of the current study were as follows: firstly, the top three most frequent overall revision aetiologies for patients who underwent THA was PJI (27.2%), aseptic loosening (25.2%), and wear (15.2%). Secondly, the most common cause of THA revision specifically between 2009 to 2013 was aseptic loosening (28.6%), while the most common cause between 2014 to 2019 was PJI (27.3%). Thirdly, THA revisions for adverse local tissue reaction resulting in osteolysis was significantly more frequent in the 2014 to 2019 time period, while the frequency of revision THA for aseptic loosening was significantly greater between 2009 to 2013. Finally, a secondary vetting process was required to accurately define the percentage breakdown of diagnoses, which may have exposed some concerns with large database studies that do not undergo these processes.

PJI occurred in 794 (27.2%) patients over the ten-year study period, making it the most frequent revision aetiology for patients who underwent THA. Kee et al[15] analyzed 128 revision THA over a one-year time period and reported that the most frequent cause for revision was infection (40.4%). Likewise, Kelmer et al[16] found that of 444 revision hip procedures performed from 2010 to 2019 at their institution, the overall PJI burden resulting in revision was 9.9%, and that infections were more common in the first two years after a primary THA procedure. By comparison, a few national database studies using the National Inpatient Sample (NIS) database have found that the two most common causes for THA revisions were due to aseptic loosening and dislocation.[3,9] The differences across previously noted findings highlight inherent limitations of database studies, such as limited clarity in indications for surgery and patient selection, which may account for differences in results. Regardless, it is notable that despite extensive investments in procedures and protocols to minimize infection over the last ten years at both our institution and globally, no statistically significant changes were found in infection rates over the ten-year period at our institution when temporal stratification was performed (27.0% vs 27.3%; p = 0.89). This epidemiological finding reinforces that infection prevention still needs further exploration in order to mitigate the incidence of this devastating complication.[17,18] A targeted clinical approach to anticipate and minimize PJI that necessitates revision THA should be a quality improvement initiative of hospital systems with large surgical volumes in orthopaedics. Many of the 'additional' procedures that are required during complex revision surgery for PJI often add hours to surgery, increase the level of postoperative hospital care, and subsequently impose costs on the healthcare system, ranging from USD $28,240 to $34,300 per patient.[19,20] This is clinically significant, as over a ten-year period this approximates to an additional $22.4 to $27.2 million in cost for our institution, which may also apply to other large, high-volume arthroplasty centres.

Furthermore, the current study found that when temporally comparing all aetiologies of revision THA, only

two statistically significant differences were observed. The first was with respect to adverse local tissue reaction resulting in osteolysis. The incidence of this revision THA aetiology was greater in the 2014 to 2019 time period (4.7% vs 10.0%; $p < 0.001$) when compared to the 2009 to 2013 time period. The second was with respect to the frequency of aseptic loosening, with a higher proportion of patients experiencing aseptic loosening and requiring revision THA in the 2009 to 2013 time period (28.6% vs 21.9%; $p < 0.001$). Adverse local tissue reactions have been more prevalent with some implant designs, especially with the recent focus on diagnosing trunnionosis and metal-on-metal in modular primary hip implant devices.[21-23] This trend occurred in the late early time period (2009 to 2013) leading to greater number of revisions in the 2014 to 2019 timeframe. We have improved techniques and ingrowth surfaces, which have brought loosening down in frequency. We have also made the change in polyethylene to cross-linked polyethylene, leading to reduced wear and osteolysis, and thus decreased component loosening.

Our vetting process of the data illustrates that when determining aetiology of revision based only on coding, without further exploration of the patient chart and radiological imaging, nine aetiology categories were under-reported (dislocation, failed hemiarthroplasty converted to THA, fracture, infection, local tissue reaction, aseptic loosening, malpositioning iliopsoas tendinitis, miscellaneous, and wear), one was over-reported (mechanical failure; 22.4% vs 1.8%), and one category did not change at all in frequency (wound dehiscence; 0.2% vs 0.2%) (Table I). The most substantial finding of this analysis was the extent of inflation to the mechanical failure aetiology in the original dataset. Bozic et al[3] performed a review of the NIS database for 235,857 revision THAs from 2005 to 2010 and categorized their mechanical reasons for revision as implant failure (10%), other mechanical problems (8%), and other mechanical complications (5%). These reasons for revision alone account for 55,291 patients (23%) of their entire dataset for THAs, yet do not address any further differences between the categories at a level that can allude to true complications resulting in another procedure. The current study also highlights significant limitations that may exist when interpreting large database studies. For example, the inherent complexities of coding, which do not always align with the actual procedure performed, present a challenge for researchers and clinicians evaluating the epidemiology of these implants. Global trends seen in large database studies that do not vet the data to the extent that we did, and do not match our epidemiological experience, present a potential confounder in understanding aetiological trends of hip arthroplasty revisions at a granular level.

Understanding the epidemiology of revision arthroplasty may help elucidate the relationships between complexity of revision and reimbursement in a healthcare system that continues to shift towards value-based health care.[24] The most recent American Joint Replacement Registry (AJRR) analysis by the American Academy of Orthopaedic Surgeons determined the mean number of revision hip arthroplasty procedures performed annually by surgeons in the registry was 3.4 (1 to 4).[25] This revision burden may be exponentially greater for surgeons at large urban tertiary referral centres than is reported in the AJRR. As the field of THA continues to evolve, changes in implant design, preoperative optimization, and postoperative protocols (i.e. outpatient surgery) may have unintended consequences that impact the aetiologies necessitating revision THA.

It is important to follow these changes in practice and their impact on revision THA procedures over time. These differences may have implications across the USA for the way in which surgeons determine how to balance their revision surgical volume and may highlight the potential for "cherry picking" regarding their surgical candidates. We advocate for this information to be used in a mutually constructive way, whereby hip surgeons and large institutions that experience high volumes of revisions receive adjusted bundled payments to reflect the increased risk and challenges associated with these procedures. One way to specifically address this current problem is to have physicians review coding at a high level without administrators or coding departments changing procedural and diagnosis codes to optimize billing. This is a problem in the USA which we believe to a certain extent could occur in any large registry, ultimately blurring the reality of what surgeons are being reimbursed for, the complexity of the revision procedure, and the ultimate aetiology of the failed arthroplasty. Demonstration of the dichotomy that exists between complexity of patient case and reimbursement with thorough review of patient data, as was done in this study, can be a catalyst for change in how insurers (such as Centers for Medicare and Medicaid in the USA) view the reimbursement model for surgeons taking on these procedures.

We note that there are several limitations to the current study, including the retrospective nature of data collection and subsequently of classifying revision indications. Furthermore, this paper highlights what was performed during revision procedures, but does not explore clinical outcomes, complications, or association between implant characteristics and revision aetiology, which may hold value in further understanding trends in and prognosis of revision THA. A total of 29 patients were excluded due to a clinical diagnosis of "Osteoarthritis", "Avascular Necrosis", and "Childhood Hip Problem," though their CPT codes indicated revision arthroplasty aetiologies. While those cases did not represent true revision procedures, these findings highlight discrepancies with the CPT code system as a whole. Data on implant design

were not available, and inherent differences that potentially existed in implant design may have contributed to differences in revision aetiologies. While this was not the primary focus of the study, a more detailed evaluation of patient factors, including implant selection, may have allowed more granular trends to be revealed as it relates to epidemiology of revisions. Lastly, this epidemiological study only represents patients from our institution and we also acknowledge that the surgical contribution from each surgeon may not have been equal. We believe that data acquired from seven different, fellowship-trained arthroplasty surgeons are valuable and contribute to the external validity of our findings as they may be applicable to diverse populations of patients receiving many different prostheses.

In conclusion, PJI was the most common cause for revision THA overall. Adverse local tissue reaction resulting in osteolysis necessitating revision THA was significantly more frequent in the 2014 to 2019 period, while aseptic loosening necessitating revision THA was significantly more frequent in the 2009 to 2013 period. Future studies will need to address the complex relationship between revision THA aetiologies and level of compensation based on RVUs or alternative payment models that adjust for these aetiologies.

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Author contributions:
- B. Kerzner: Collected the data, Conducted the statistical analysis, Wrote the manuscript.
- K. N. Kunze: Conducted the statistical analysis, Wrote the manuscript.
- M. B. O'Sullivan: Collected the data, Wrote the manuscript.
- K. Pandher: Collected the data, Wrote the manuscript.
- B. R. Levine: Collected the data, Wrote the manuscript, Senior author.

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