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Original research

Temporal Trends of Revision Etiologies in Total Knee Arthroplasty at a Single High-Volume Institution: An Epidemiological Analysis

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ABSTRACT

Background: Temporal changes in revision total knee arthroplasty (rTKA) may have implications in determining the etiology for implant failure. The purpose of this study was to 1) perform an epidemiologic analysis of etiologies that required rTKA and 2) determine whether temporal changes existed for revision over the study period.

Methods: All rTKA procedures performed at a single institution from 2009 to 2019 were analyzed. Revision procedures were stratified into 2 time periods, 2009-2013 and 2014-2019, to assess for changes over time. Patients' electronic medical record, operative report, and radiographs were reviewed to ensure diagnosis information was accurately documented in relation to the predominate etiology necessitating the revision procedure.

Results: Three thousand and nine patients undergoing rTKA between 2009 and 2019 were identified with a mean age of 64.6 years. A total of 1,666 (55.4%) patients were female, and the majority of patients were Caucasian (2,306, 76.6%). The 3 most frequent rTKA etiologies were aseptic loosening (35.1%), periprosthetic infection (33.2%), and instability (16.0%). A higher proportion of patients underwent rTKA for arthrofibrosis (5.1% vs 3.4%, $P = .023$) and periprosthetic joint infection (38.9% vs 28.6%, $P < .001$) between 2009 and 2013, while a significantly higher proportion of patients underwent rTKA for instability (12.6% vs 18.8%, $P < .001$) between 2014 and 2019.

Conclusion: Aseptic loosening was the most common cause for rTKA over the last decade. rTKA for arthrofibrosis and periprosthetic joint infection was more frequent between 2009 and 2013, while a significantly higher proportion of patients underwent rTKA for instability in 2014-2019. Future studies will need to focus on identifying and reducing risk factors for the trending causes of rTKA.

Introduction

Well-documented causes necessitating revision total knee arthroplasty (TKA) include mechanical (aseptic) loosening, bearing surface wear, dislocation/instability, infection, and implant failure [1-6]. The increasing demand for TKA in the United States will lead to a subsequent rise in the number of annual revision arthroplasty procedures [7-9]. In the American Joint Replacement Registry's (AJRR) most recent report released by the American Academy of Orthopedic Surgeons, the cumulative revision burden of participating surgeons in the registry for knee arthroplasty was 58,409 from 2012 to 2018 [10]. TKA revisions typically require longer surgical times and elevated direct and indirect costs yet are often not compensated at a rate commiserate with the level of complexity [11-15]. Furthermore, patients with multiple comorbid conditions and risk factors increase the complexity of baseline care and are an at-risk patient subpopulation for revision operations [16]. For these reasons, the demand for revision TKA services is gradually outpacing the supply of surgeons willing to perform these procedures.

Understanding temporal changes in revision TKA and epidemiologic trends from large data may have implications across the United States in how surgeons determine how to balance their surgical volume, as revision TKA has evolved into a complex balance of maximizing patient outcomes and minimizing costs [17-21]. Although previous studies have sought to determine causes

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for revision TKA, they often reflect statistics pulled from national/large databases, which have inherent limitations associated with documentation/coding, inclusion and exclusion criteria that are often not well described, and heterogeneous surgical techniques and patient populations [6]. Highly vetted data from tertiary referral institutions with a similar revision burden are therefore necessary to shed light on the causes of revision TKA before elucidating why certain trends in revision are occurring, which may ultimately impact policy changes on procedural reimbursement.

The purpose of the present study was to 1) perform an epidemiologic analysis of etiologies that required revision TKA procedures and 2) to determine whether temporal changes existed with these revision etiologies over the study time period. The authors hypothesized that complications requiring revision knee procedures when temporally stratified would show decreased complications in the latter half of the study period because of improvements in implant design, operative planning, patient education, and postoperative therapy and medical management.

Material and methods

Identification of study population

Institutional review board approval was obtained before performing a retrospective review of all patients at our institution who underwent revision TKA between January 1, 2009, and September 19, 2019. Patient cases were queried from a large institutional total joint arthroplasty registry and extracted based on matched Current Procedural Terminology (CPT) codes for knees (27,486, 27,487, 27,488). Inclusion criteria included male or female and who had received a previous TKA procedure and a subsequent revision surgery. A total of 7 fellowship-trained arthroplasty surgeons contributed to this large institutional registry. All 7 surgeons in this study have a robust revision practice, with the newest surgeon, who also has the least number of total revisions, comprising about 5% of all revisions. Some of the surgeons had a large number of revisions earlier on in the study, while others took on a greater revision burden in the latter half. The initial query identified a total of 3024 total knee revision arthroplasty procedures over the study period.

Data were systematically refined based on diagnosis/coding information, and patients that underwent anything other than a revision TKA were noted to be miscoded and removed from the study. Patient information that was pooled and repeated because of clerical error was also removed from the study to ensure accurate representation of the patient population. Modes of failure as well as repeated patients due to clerical error were among the 15 diagnoses on initial review that were deemed false causes of revision arthroplasty and thus were removed from further analysis. Further analysis was performed to ensure the CPT and diagnosis codes in the patients' chart represented the true etiology of revision. Diagnoses (mode of failure) in knee revisions were then systematically analyzed further by 2 trained research coordinators who were not involved in any treatment of the patients enrolled in the study. Patients' electronic medical records, including details of the operative report and radiographic imaging, were reviewed to ensure diagnosis information was accurately documented in relation to the primary etiology necessitating the revision procedure that was performed. The breakdown of overall etiologies of revision from the original data set and the final data set after further analysis is shown in Table 1.

Data collection

Demographic information including date of surgery, age, race, and mode of implant failure was obtained for all patients (Tables 2 and 3). Data for revision knee revision arthroplasty procedures were stratified into 2 time periods based on date range: 2009-2013 and 2014-2019. The number of patients in each time period was not exactly equal as the primary focus was on the etiologies of revision, while changes in revision etiology over time were a subanalysis. Diagnoses (modes of failure) for knees requiring revision procedures included arthrofibrosis, extensor mechanism failure, fracture, infection, instability, loosening, mechanical failure, unicompartmental arthroplasty converted to full TKA, wear, and wound dehiscence.

Table 1
Raw data composition of etiologies of revision knee arthroplasty.

Etiology	Raw data, N (%)	Final data after secondary analysis, N (%)
Arthrofibrosis	36 (1.2)	125 (4.2)
Extensor mechanism failure	10 (0.3)	52 (1.7)
Fracture	42 (1.4)	49 (1.6)
Infection	984 (32.5)	1000 (33.2)
Instability	270 (8.9)	482 (16.0)
Aseptic loosening	783 (25.9)	1055 (35.1)
Mechanical failure	789 (26.1)	29 (1.0)
Miscellaneous	3 (0.1)	17 (0.6)
Unicompartmental arthroplasty converted to full TKA	8 (0.3)	81 (2.7)
Wear	82 (2.7)	94 (3.1)
Wound dehiscence	17 (0.6)	25 (0.8)
Total	3024	3009

Statistical analysis

Revision etiology frequency was quantified for TKA independently and presented as frequencies with percentages. After temporal stratification of TKA patients, revision etiology frequencies were compared using chi-squared analysis of associations. If the total frequency of events for a revision etiology was less than 5, the Fischer's exact test was performed. Continuous data were compared using independent t-tests. All analyses were performed using Stata version 16.1 (College Station, TX). Statistical significance was considered a P value less than 0.05.

Results

Revision total knee arthroplasty: epidemiology

A total of 3009 patients undergoing revision TKA between January 1, 2009, and September 19, 2019, were identified with a mean age of 64.6 (range: 28-98) years. A total of 1666 (55.4%) patients were female, and the majority of patients were Caucasian (n = 2306; 76.6%). The average number of revisions performed each year over the study period was 278.4. In the original data set before

Table 2
Knee demographics.

Ethnicity	2009-2013, N (%)	2014-2019, N (%)
White	970 (72.1)	1336 (80.3)
Black or African American	162 (12.0)	210 (12.6)
Asian	7 (0.5)	10 (0.6)
American Indian	3 (0.2)	2 (0.1)
Hispanic	65 (4.8)	35 (2.1)
Other/did not indicate	138 (10.3)	71 (4.3)
Gender		
Male	571 (42.5)	772 (46.4)
Female	774 (57.5)	892 (53.6)
Age		
Max	92	98
Min	30	28
Average	63.9	65.2

Table 3
Knee etiologies of revision and demographics.

Etiology with stratification	Average age (y)	Gender (M/F)	Incidence (n)
Arthrofibrosis			
2009-2013	59.4	26/42	68
2014-2019	64.0	22/35	57
Extensor mechanism failure			
2009-2013	68.5	7/12	19
2014-2019	68.8	11/22	33
Fracture			
2009-2013	72.0	2/18	20
2014-2019	71.3	8/21	29
Infection			
2009-2013	64.5	263/261	524
2014-2019	65.2	292/184	476
Instability			
2009-2013	63.1	47/122	169
2014-2019	64.7	122/191	313
Aseptic loosening			
2009-2013	63.5	187/260	447
2014-2019	65.2	249/359	608
Mechanical failure			
2009-2013	59.6	2/7	9
2014-2019	61.1	9/11	20
Miscellaneous			
2009-2013	66.6	1/6	7
2014-2019	64.7	6/4	10
Unicompartmental arthroplasty converted to full TKA			
2009-2013	62.5	12/19	31
2014-2019	66.2	25/25	50
Wear			
2009-2013	68.2	20/23	43
2014-2019	66.9	21/30	51
Wound dehiscence			
2009-2013	59.0	4/4	8
2014-2019	64.6	7/10	17

a thorough review of the patient medical record and radiographic imaging, infection (n = 984; 32.5%), mechanical failure (n = 789; 26.1%), and aseptic loosening (n = 783; 25.9%) were the 3 most common causes necessitating revision (Table 1). The mechanical failure category was the third most common diagnosis in the original data set and the third least common diagnosis in the finalized data set (26.1% vs 1.0%). Increases in the finalized data set compared to the original raw data were observed for arthrofibrosis (1.2% vs 4.2%), extensor mechanism failure (0.3% vs 1.7%), fracture (1.4% vs 1.6%), infection (32.5% vs 33.2%), instability (8.9% vs 16.0%), aseptic loosening (25.9% vs 35.1%), unicompartmental arthroplasty converted to full TKA (0.3% vs 2.7%), wear (2.7% vs 3.1%), and wound dehiscence (0.6% vs 0.8%). The most frequent revision etiology in the finalized data set was aseptic loosening (n = 1055; 35.1%), followed by periprosthetic joint infection (n = 1000; 33.2%) and instability (n = 482; 16.0%). The number and percentages of other revision etiologies are listed in Table 4.

Revision total knee arthroplasty etiology: temporal trends

The study period was stratified into early (2009-2013) and late (2014-2019) time periods. A total of 1345 patients underwent revision TKA between 2009 and 2013, while a total of 1664 patients underwent revision TKA between 2014 and 2019. After stratification, no statistically significant differences were observed in age, sex, or race. Chi-squared analysis of association demonstrated that a significantly higher proportion of patients underwent revision TKA for arthrofibrosis (5.1% vs 3.4%, $P = .023$) and periprosthetic joint infection (38.9% vs 28.6%, $P < .001$) in the 2009-2013 time period than in the 2014-2019 time period, while a significantly higher proportion of patients underwent revision TKA for instability (12.6% vs 18.8%, $P < .001$) in the 2014-2019 period. Revision TKAs for extensor mechanism failure (1.4% vs 2.0%, $P = .23$), periprosthetic fracture (1.5% vs 1.7%, $P = .58$), aseptic loosening (33.2% vs 36.5%, $P = .059$), mechanical failure (0.7% vs 1.2%, $P = .14$), unicompartmental arthroplasty converted to full TKA (2.3% vs 3.0%, $P = .24$), excessive wear (3.2% vs 3.1%, $P = .84$), wound dehiscence (0.6% vs 1.0%, $P = .20$), and miscellaneous causes (0.5% vs 0.6%, $P = .77$) were not significantly associated with either time period.

Discussion

This study analyzed 3009 patients undergoing revision TKA from 2009 to 2019 to understand the etiology in revision procedures at our institution. The major findings of the present study were as follows: 1) the most frequent overall revision etiologies for patients who underwent TKA were aseptic loosening (35.1%); 2) the most common cause of revision TKA between 2009 and 2013 was periprosthetic joint infection (38.9%), while the most common cause between 2014 and 2019 was aseptic loosening (36.5%); 3) TKA revisions for arthrofibrosis and periprosthetic joint infection were significantly more frequent between 2009 and 2013 than in the 2014-2019 time period, while a significantly greater proportion of patients underwent revision TKA for instability during the 2014-2019 period.

The most frequent overall etiology of revision TKA was aseptic loosening, which occurred in 1055 (35.1%) patients. While no statistically significant changes were observed when patients with aseptic loosening were stratified temporally, the results of the present study are comparable to previously described literature [3,4,6,22-24]. Delanois et al. analyzed the National Inpatient Sample database and determined that the 2 most common causes necessitating revision TKA were periprosthetic infection (20.4%) and aseptic loosening (20.3%) [6]. In addition, Sharkey et al.

Table 4
Temporal stratification and percentage breakdown of all knee revisions.

Etiology	2009-2013 TKA, N (%)	2014-2019 TKA, N (%)	Overall TKA, N (%)	*P* value
Arthrofibrosis	68 (5.1)	57 (3.4)	125 (4.2)	.023
Extensor mechanism failure	19 (1.4)	33 (2.0)	52 (1.7)	.23
Fracture	20 (1.5)	29 (1.7)	49 (1.6)	.58
Infection	524 (38.9)	476 (28.6)	1000 (33.2)	.001
Instability	169 (12.6)	313 (18.8)	482 (16.0)	.001
Aseptic loosening	447 (33.2)	608 (36.5)	1055 (35.1)	.059
Mechanical failure	9 (0.7)	20 (1.2)	29 (1.0)	.14
Miscellaneous	7 (0.5)	10 (0.6)	17 (0.6)	.77
Unicompartmental arthroplasty converted to full TKA	31 (2.3)	50 (3.0)	81 (2.7)	.24
Wear	43 (3.2)	51 (3.1)	94 (3.1)	.84
Wound dehiscence	8 (0.6)	17 (1.0)	25 (0.8)	.20
Total	1345	1664	3009	

performed a single institution analysis of 781 revision TKAs over a 10-year period and found that aseptic loosening (39.9%) was the most common complication necessitating revision TKA, followed by periprosthetic joint infection (27.4%) [24]. Clinically, the high rates of aseptic loosening resulting in revision TKA present a tremendous financial burden as hospitalization alone for revision TKA has been reported between $23,130 and $36,643 [9]. While our experience has similar trends to both national database and institutional-based data, the large proportion of patients necessitating revision TKA for aseptic loosening highlight the need to better understand the biomechanical properties of the knee, the mechanical forces subjected to the implant-bone interface during movement, and the complex interactions between soft-tissue balancing, component alignment, and implant longevity.

Furthermore, this study highlighted the importance of study design and meticulous review of patient data to depict an accurate picture of the epidemiologic data. We saw drastic changes in proportion of etiology requiring revision from the raw data set compared with the finalized data set after extensive review of both the electronic medical record and radiographic imaging (Table 1). Our experience highlights limitations in large data base studies that are unable to isolate certain causes of revision. Large database studies that have used the National Inpatient Sample database found that ICD codes such as "Other mechanical complication of the prosthetic implant", "Other mechanical complication of other internal orthopedic device implant or graft", or "Other complications due to internal joint prosthesis" composed 131,654 (30.4%) patients of their overall data set. This substantial portion of the data did not allow for extracting certain frequencies, such as implant failure secondary to polyethylene wear [6]. This highlights that large database studies have limitations in the investigation of the epidemiological data in revision TKA as granular conclusions may not be possible.

When all TKA revision etiologies were temporally stratified, a significantly higher proportion of patients underwent revision TKA for arthrofibrosis and periprosthetic joint infection in the 2009-2013 time period than in the 2014-2019 time period, while a significantly higher proportion of patients underwent revision TKA for instability in the 2014-2019 period than in the 2009-2013 time period. At our institution, infection may be improved because of preoperative optimization protocols and wellness clinic referrals. Instability, such as mid-flexion instability has been a more popular diagnosis in recent years and may explain some of the temporal changes [25-27]. This change in the language of these revision types has to be put in context with the data collection time period. The change to include a wider range of accepted etiologies of revision highlights that while the proportion of this diagnosis type has changed over time, they may actually be skewed as the development of accepted diagnoses by surgeons inherently evolves with greater prosthetic biomechanical understanding.

Understanding the epidemiology of revision arthroplasty may help elucidate the relationships between complexity of revision and reimbursement in a health-care system that continues to shift toward value-based health care. Gabor et al. found that implementation of a dedicated revision TKA service would lead to lower surgeon reimbursement with the current fee-for-service model [28]. The most recent AJRR analysis by the American Academy of Orthopedic Surgeons determined the mean number of revision knee arthroplasty procedures performed annually by surgeons in the registry was 5.4 (range:1-6) [10]. This revision burden may be exponentially greater for surgeons at large urban tertiary referral centers than is reported in the AJRR. These differences may have implications across the United States in how surgeons determine how to balance their revision TKA surgical volume and may highlight the potential for "cherry picking" regarding their surgical volume. We advocate for other tertiary referral centers to investigate and publish their data on the etiologies of revision arthroplasty. Indeed, careful data analysis of TKA revision etiologies may hold important information that may influence TKA reimbursement models as opposed to simply interpreting large-scale data sets. Similar results from other large, tertiary centers would provide strong evidence that revision TKA needs more attention to vetting and presenting the data that reimbursements are based on.

We note that there are several limitations to the present study. First, a total of 15 patients were excluded because of a clinical diagnosis of "osteoarthritis," "avascular necrosis," and "childhood knee problem," although their CPT codes indicated revision arthroplasty etiologies. While those cases did not represent true revision procedures, these findings highlight discrepancies with the CPT code system as a whole (Table 1). Second, data on implant design were not available, and inherent differences that potentially existed in implant design may have contributed to differences in revision etiologies. 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. Third, this epidemiological study only represents patients from our institution. We believe that data acquired from 7 different, fellowship-trained arthroplasty surgeons are valuable and reinforce the need for centers handling a large revision burden to complete a review of their data, similar to this present study, to influence change in revision TKA reimbursement models. However, further research is warranted, as the present study did not model the financial implications of revision arthroplasty burden. Therefore, given the current data, the present study cannot comment on policy changes or the financial adjustments necessary in centers with similar burdens. Rather, we recommend that other institutions examine their revision arthroplasty etiologies for similar trends, as external validation of such etiologies may provide stronger evidence to change policy.

Conclusions

Aseptic loosening was the most common cause for TKA revision. Revision TKA for arthrofibrosis and periprosthetic joint infection was more frequent between 2009 and 2013, while a significantly higher proportion of patients underwent revision TKA for instability in 2014-2019. Future studies will need to address the complex relationship between revision TKA etiologies and level of compensation based on relative value units or alternative payment models that adjust for these etiologies.

Conflicts of interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Benjamin Kerzner, BS: None. Kyle Kunze, MD: Editorial/governing board of Arthroscopy. Michael O'Sullivan, MD: One time $1500 fee to serve as faculty at outgoing/incoming fellow conference by DJO. Karan Pandher, BS: None. Brett Levine, MD, MS: Paid consultant for a company or supplier of Exactech, Merete, Link; research support from Zimmer- Biomet; royalties and financial or material support from publishers Human Kinetics and Slack Inc; medical/orthopaedic publications editorial/governing board of Arthroscopy-Editorial Board Member and Arthroplasty Today and JOA and Orthopedics; board member/committee appointments for a society including AAHKS—Patient education and research committees, AAOS—Hip and knee evaluation committee and MAOA—Education committee. Brett R. Levine, MD, MS serves as the

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