The Journal of Arthroplasty 33 (2018) 407–414

Contents lists available at ScienceDirect

The Journal of Arthroplasty

journal homepage: www.arthroplastyjournal.org

Primary Arthroplasty

Failure After Modern Total Knee Arthroplasty: A Prospective Study of 18,065 Knees

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ARTICLE INFO

Article history:
Received 9 August 2017
Received in revised form
16 September 2017
Accepted 18 September 2017
Available online 25 September 2017

Keywords:
primary total knee arthroplasty failure
aseptic loosening
arthrofibrosis
instability
osteolysis

ABSTRACT

Background: We sought is to determine the mechanism of failure among primary total knee arthroplasties (TKAs) performed at a single high-volume institution by asking the following research questions: (1) What are the most common failure modes for modern TKA designs? and (2) What are the preoperative risk factors for failure following primary TKA?
Methods: From May 2007 to December 2012, 18,065 primary TKAs performed on 16,083 patients at a single institution were recorded in a prospective total joint arthroplasty registry with a minimum of 5-year follow-up. We retrospectively reviewed patient charts to determine a cause of failure for primary TKAs. A cox proportional hazard model was used to determine the risk of revision surgery following primary TKA.
Results: The most common reasons for failure within 2 years after TKA were infection and stiffness. The multivariable regression identified the following preoperative risk factors for TKA failure: history of drug abuse (hazard ratio [HR] 4.68; $P = 0.03$), deformity/mechanical preoperative diagnosis (HR 3.52; $P < .01$), having a constrained condylar knee implant over posterior-stabilized implant (HR 1.99; $P < .01$), post-traumatic/trauma preoperative diagnosis (HR 1.78; $P = .03$), and younger age (HR 0.61; $P < .01$)
Conclusion: These findings add to the growing data that primary TKAs are no longer failing from polyethylene wear-related issues. This study identified preoperative risk factors for failure of primary TKAs, which may be useful information for developing strategies to improve outcomes following TKA.

The number of total knee arthroplasties (TKA) performed over the last decade has dramatically increased, and will continue to do so with some projection estimates to be around 3 million per year in the United States by the year 2030 [1]. With an ever increasing number of primary TKAs being performed, there will be a concurrent predictable increase in TKA failures and thus revision total knee surgeries. Several studies attempted to elucidate preoperative and postoperative factors and the influence of implant design to determine causes of TKA failure [2,3]. Bozic et al [4] studied the epidemiology of TKA revision surgeries using the Nationwide Inpatient Sample database and found that the 3 major reasons for revision were infection (25%), mechanical loosening (16%), and implant failure (10%). Fehring et al [5] found that early failures were attributed to infection 38% of the time, 27% to instability, 13% to failure of ingrowth of a porous-coated implant, and 8% to patellofemoral issues. The authors advised against the use of cementless prosthesis because of the early failures in their series. In a similar paper by Sharkey et al [3], the major causes for revision were polyethylene wear (25%), aseptic loosening (24%), instability (21%), infection (18%), arthrofibrosis (15%), malalignment (12%), and extensor mechanism deficiency (7%). Those authors recommended

One or more of the authors of this paper have disclosed potential or pertinent conflicts of interest, which may include receipt of payment, either direct or indirect, institutional support, or association with an entity in the biomedical field which may be perceived to have potential conflict of interest with this work. For full disclosure statements refer to https://doi.org/10.1016/j.arth.2017.09.041.

All work was performed at the Hospital for Special Surgery.

Ethical Board Review statement: Institutional ethical board review was obtained for this study.

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https://doi.org/10.1016/j.arth.2017.09.041
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the abandonment of tibial surface cementing, but could not explain why such a large polyethylene failure rate occurred in their series. These studies could not provide information on preoperative risk factors for failure, since they were reports from tertiary centers which did not perform many of the original surgeries. Thus, generalizations about causes of primary knee failure would be subject to bias.

Current registry databases are an important tool for collecting patient-related information for analytic purposes. Registry data are becoming recognized as significant in studying epidemiology, cost effectiveness, and payer reimbursement with regard to TKA [6,7]. The limitations to such databases are influenced by the quality of the collected data and the patient's commitment to providing follow-up surveys from the same institution.

Our institution has a prospectively collected database that includes all demographic and clinical patient information for patients who underwent TKA at our center over a 5-year span from May 2007 to December 2012. The data in the registry provided us the unique opportunity to determine the causes of early failure among primary TKAs performed at a single institution, free from the bias inherent in data from revision TKA at tertiary referral centers. Our hope was that we might identify possible solutions to prevent early failure of TKAs at our institution. We asked the following research questions: (1) What are the most common failure modes for modern TKA designs? and (2) What are the preoperative risk factors for failure following primary TKA?

Patients and Methods

From May 2007 to December 2012, 18,065 primary TKA surgeries performed on 16,083 patients at a single institution were recorded in an Institutional Review Board-approved prospective total joint arthroplasty registry. As of January 31, 2016, 417 primary TKAs returned to our institution to undergo revision surgery. Of the 417 primary TKAs that were identified as failures, 12 were excluded because they underwent isolated irrigation and debridement for hematoma without removal of components. Isolated polyethylene exchange for infection was included in the study. Therefore, we identified failure mechanisms in 405 knees in 400 patients (Fig. 1).

We retrospectively reviewed patient electronic medical records, paper medical charts, radiographic data, and laboratory results to determine a cause of failure for primary TKAs. Radiographic data included preoperative and postoperative radiographs, computed tomography, and magnetic resonance imaging images when available. Laboratory results included erythrocytes sedimentation rate, C-reactive protein, white cell count, and synovial fluid culture and cell counts.

We extracted clinical information about patient demographics, comorbidities including the Charlson Comorbidity Index (CCI), diagnosis for the primary TKA surgery, and TKA design using data from the arthroplasty registry and patient electronic medical records. Comorbidities and diagnosis were determined using International Classification of Diseases, Ninth Revision (ICD-9) diagnosis codes. A history of drug abuse was captured by both ICD-9 codes and in a preoperative questionnaire given to every patient in the study. We used 4 categories for original diagnosis for the primary TKA surgery: (1) osteoarthritis (OA) and avascular necrosis, (2) rheumatoid arthritis (RA) and inflammatory arthritis, (3) traumatic and post-traumatic arthritis, and (4) dysplasia, deformity, mechanical failure, or unknown reasons.

We categorized TKA designs into levels of constraint, including posterior-stabilized (PS), cruciate-retaining (CR), constrained condylar knee (CCK), hinge, or unknown. The implant models and numbers used in our study included the following: 26 Exactech (Gainesville, FL) nonmodular CCK, 62 Exactech PS, 3 Exactech Hi-flex, 70 Exactech Optetrak Logic, 1 Wright Medical Advance (Memphis, TN), 27 Zimmer (Warsaw, IN) NexGen LPS, 20 Zimmer NexGen LPS Flex, 4 Zimmer NexGen Legacy CCK, 9 Zimmer NexGen Gender Specific LPS flex, 11 Smith & Nephew (Memphis, TN) Journey, 102 Smith & Nephew Genesis II SPC, 24 Smith & Nephew Legion, 21 DePuy (Warsaw, IN) Sigma, 1 DePuy S-ROM Noiles Rotating Hinge, 3 Stryker (Mahwah, NJ) Triathlon, 1 Ortho Development (Draper, UT) Balanced knee, 1 Encore Medical (Austin, TX), and 19 Biomet (Warsaw, IN) Vanguard.

Statistics

Patient demographics, comorbidities, diagnoses, and TKA designs were compared between patients who failed and those did not fail using two-sample t-test or chi-squared test. Time to revision after primary knee arthroplasty was analyzed using the Kaplan-Meier method. We also compared time to revision among diagnoses and TKA designs in failed TKAs. A Cox proportional hazard model was used to study the risk factors for increased risk of revision following primary TKA. Covariates that were significant in bivariate comparisons were included in the Cox model. Results were summarized using a hazard ratio and its 95% confidence interval (CI).

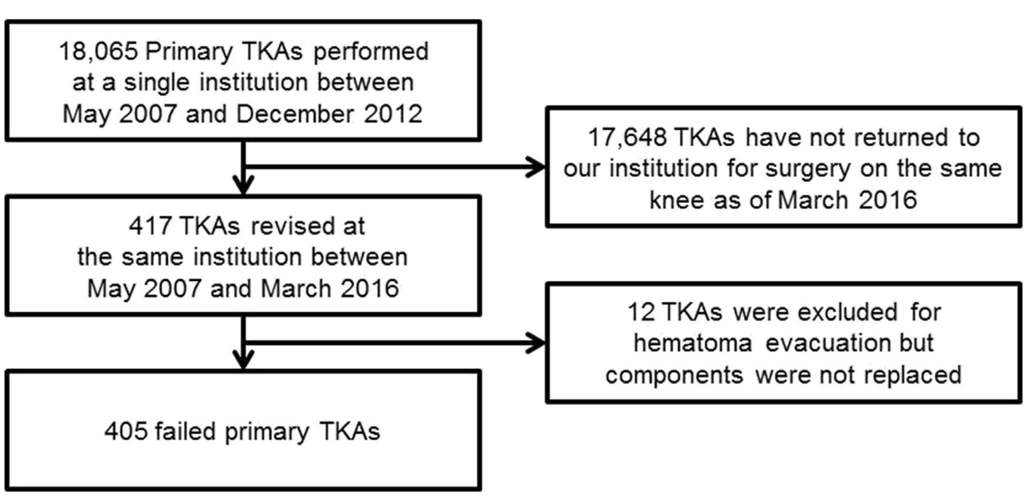

Fig. 1. Flow diagram of patients included in the study.

Table 1
Mechanisms of Failure After Total Knee Arthroplasty.

Reason for Failure	No. of Failures/% of Failures	Average Time of Implantation (mo)
Infection	103/25.4	20
Instability	97/24	27
Aseptic loosening	86/21.2	37
Stiffness	57/14.1	16
Periprosthetic fracture	14/3.5	29
Osteolysis/PE wear	10/2.5	27
Malalignment	10/2.5	13
Pain	5/1.3	30
Isolated loose patella	6/1.5	46
Documented nickel allergy	3/0.7	23
Patellar AVN	2/0.5	11
PE dissociation	4/1	12
Extensor mechanism failure	1/0.25	12
Patellar malposition	1/0.25	19
Peripatellar fibrosis/“clunk”	2/0.5	20
Patellar instability	1/0.25	7

AVN, avascular necrosis; PE, polyethylene.

Results

In our study, we had a total of 400 patients (405 knees) who underwent revision TKA and 17,660 TKAs that were not revised in our study period. Patients who were revised did not differ in terms of body mass index (BMI), gender, or CCI compared to patients who were not revised. However, patients in the revised cohort were younger, more likely to have a post-traumatic/traumatic diagnosis, and/or a deformity diagnosis.

The average time to revision surgery for this study was 25 months (standard deviation 20 months). Our reasons for failure were infection (25.7%), instability (24.4%), aseptic loosening (21.2%), stiffness (14.1%), periprosthetic fracture (3.5%), osteolysis/polyethylene wear (2.5%), malalignment (2.5%), isolated loose patellar component (1.5%), pain (1.3%), polyethylene dissociation (1%), metal allergy (0.7%), patellar avascular necrosis (0.5%), peripatellar fibrosis (0.5%), extensor mechanism failure (0.2%), patellar component malposition (0.2%), and patellar instability (0.2%). More than 50 patients were revised for each of our top 4 reasons for failure (Table 1). Patients who were revised for stiffness failed early with an average time to revision surgery of 16 months, compared to patients who failed for infection after 20 months, instability after 27 months, and aseptic loosening after 37 months (log-rank *P*-value <.0001) (Fig. 2). The rate of revision surgery was 2% for patients with OA/AVN, 4% with RA/inflammatory arthritis, 6% with post-traumatic arthritis, and 9% with a preoperative diagnosis for another reason (Log-Rank *P*-value <.0001) (Fig. 3). Factors that increased the risk for TKA failure based on bivariate analyses were younger age, an original diagnosis of post-traumatic osteoarthritis OA, a history of drug abuse, simultaneous bilateral TKA surgery, and the use of a CCK implant design (Table 2). Applying Cox hazard analysis to our cohort of patients showed that advancing age was protective against TKA failure with a hazard ratio of 0.61 (95% CI 0.56-0.67, $P < .01$) for every 10 years of increasing age (Table 3). Compared to patients with the preoperative diagnosis of OA/AVN, patients with post-traumatic/traumatic or dysplasia/deformity/mechanical diagnoses were 1.8 times (95% CI 1.0-3.0) and 3.5 times (95% CI 1.4-8.8) more likely to undergo revision surgery respectively. A patient with a history of drug abuse was 5 times (95% CI 1.2-19.0) more likely to undergo revision surgery. Patient gender, BMI, CCI, alcohol abuse, obesity, depression, diabetes, renal failure, cardiac disease, pulmonary disease, or neurological disorders were not associated with an increased risk of failure. CCK implants were 2 times (95% CI 1.5-2.7) more likely to undergo revision surgery than PS implants. No difference was found in failure among other implant designs.

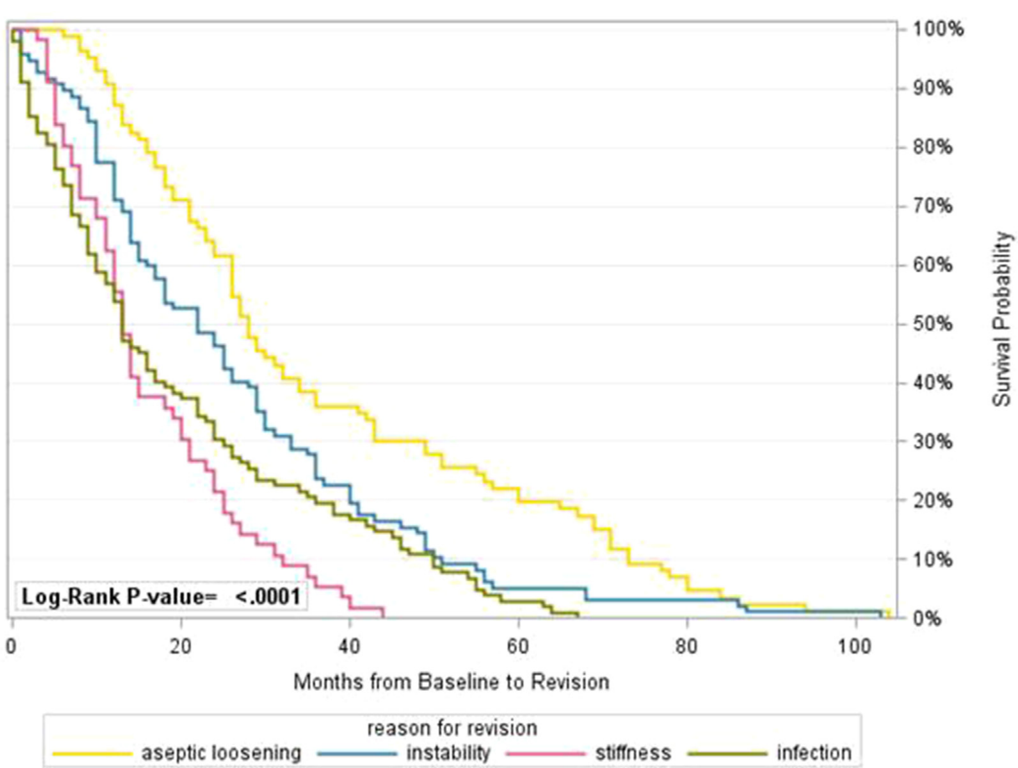

Fig. 2. Kaplan-Meier survival graph for reasons for failure. Log-rank test-nonparametric test that compares survival distributions. A $P < .05$ indicates that there is a difference between survival curves.

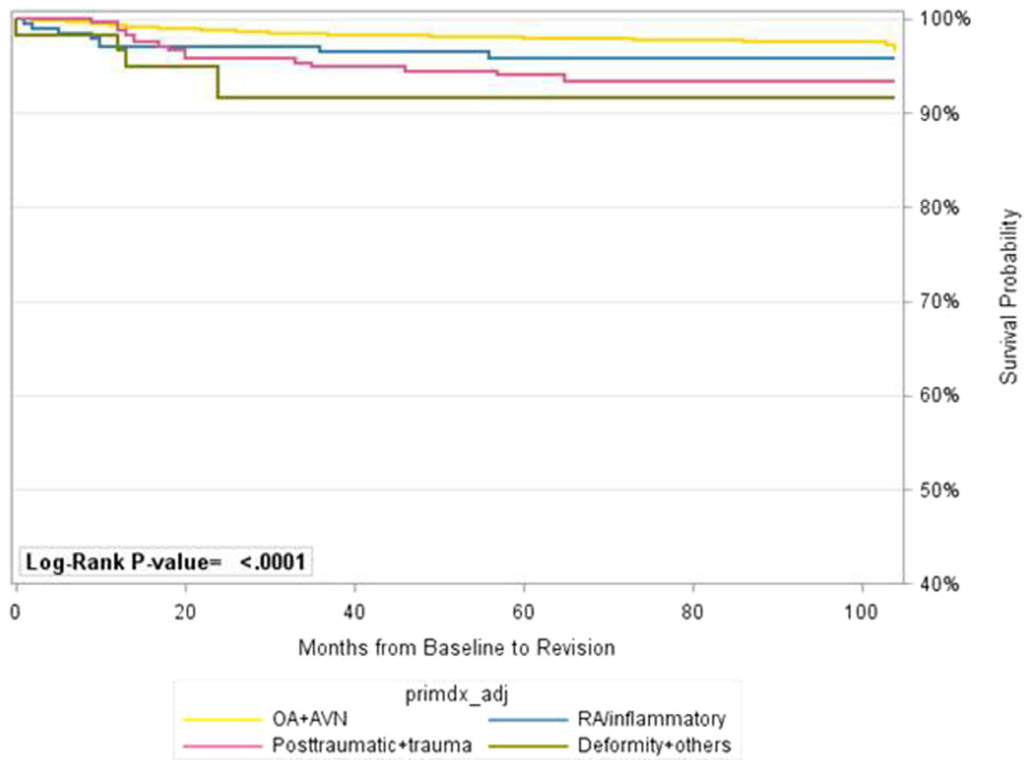

Fig. 3. Kaplan-Meier survival graph for preoperative diagnosis. Log-rank test-nonparametric test that compares survival distributions. A $P < .05$ indicates that there is a difference between survival curves.

There was an increased proportion of bilateral TKAs in the revised cohort compared to the nonrevised cohort (Table 2). However, simultaneous bilateral TKA was not a significant risk factor in the multivariate analysis. The reasons why bilateral TKAs failed were instability (17 TKAs), aseptic loosening (13), infection (14), stiffness (8), fracture (3), malalignment (1), pain (1), and metal allergy (1) (Table 4).

Discussion

The reasons for failure for primary TKA have evolved as implant designs, materials, and surgical technique have improved. Earlier studies revealed polyethylene wear and osteolysis [3] as major causes for revision, while more recent studies have pointed to infection and instability as more frequent reasons [8]. Presumably, new forms of polyethylene manufacturing and sterilization have improved the material's wear behavior and thus decreased the rate of polyethylene-related failures [9]. In our study, we defined failure as a primary TKA that went on to revision knee surgery. We found the major causes for revision to be infection followed by instability, aseptic loosening, and stiffness. As expected, the time of revision was shorter for patients revised for stiffness, infection, malalignment, and patellar instability, and longer for patients revised for aseptic loosening, isolated loose patellar component, and pain. Time to revision has been previously correlated with reason for failure, with previous studies showing that early failures (<1 year) were predominantly from infection, intermediate failures (1-3 years) were most commonly due to malalignment, and late failures (>3 years) were due to aseptic loosening [8].

Comparing studies on TKA failures can be challenging since there are different methods for describing reasons for revision surgery, surgical technique and implant designs. We have provided a summary table, with the majority of studies showing either loosening or infection as the most common cause of TKA failure (Table 5). Fehring et al [5], in their study of 440 patients who underwent revision TKA at their institution within 5 years of their index procedure, found the major reasons for early failure to be infection (38%), instability (27%), failure of ingrowth of a noncemented component (13%), and patellofemoral problems (7%). Sharkey et al [3] retrospectively reviewed 203 patients who had revision TKA over a 3-year period at their institution and found the major reasons to be polyethylene wear (25%), aseptic loosening

Table 2
Patient Factors and Risk of Failure After Primary TKA.

Patient Factors	All Patients (n = 18,065)	Not Revised (n = 17,660)	Revised (n = 405)	*P*-Value
Age (mean ± SD)	67 ± 10	68 ± 10	62 ± 10	**<.001**
% Female	63.9%	63.9%	62.8%	.62
BMI (mean ± SD)	31 ± 6	31 ± 6	31 ± 6	.25
Bilateral knees	11%	11%	14%	**.04**
Primary diagnosis	97% OA, 1% RA, 1% post-traumatic, 0.3% other	97% OA, 1% RA, 1% post-traumatic, 0.3% other	93% OA, 2% RA, 4% post-traumatic, 1% other	**<.001**
% Drug abuse	0.1%	0.1%	0.5%	**.01**

Bold values indicate those *P* values that are less than .05.
SD, standard deviation; OA, osteolysis; RA, rheumatoid arthritis.

Table 3
Cox Hazard Analysis.

Parameter		Standard Error	*P*-Value	Hazard Ratio	95% CI	
Age		0.01	<.01	0.61	0.56	0.67
Gender	Male vs female	0.11	.80	–		
BMI		0.01	.89	–		
Primary diagnosis	RA/inflammatory vs OA/AVN	0.39	.98	–		
	Post-traumatic/traumatic vs OA/AVN	0.27	.03	1.78	1.04	3.02
	Deformity/mechanical/unknown vs OA/AVN	0.47	.01	3.52	1.41	8.76
Component type	CCK vs PS	0.15	<.01	1.99	1.48	2.67
	CR vs PS	0.58	.75	–		
	Hinge vs PS	1.03	.77	–		
	Others vs PS	272.74	.97	–		
Surgery	Bilateral vs unilateral	0.15	.66	–		
Alcohol abuse	Yes vs no	1.01	.93	–		
Drug abuse	Yes vs no	0.71	.03	4.68	1.15	18.95

CR, cruciate-retaining; AVN, avascular necrosis; OA, osteolysis.

(21.1%), instability (21.2%), infection (17.5%), arthrofibrosis (14.6%), and malalignment (11.8%). These authors published an updated review a decade later of 781 revision TKAs performed over a 10-year period [10]; the reasons for revision had changed to be aseptic loosening (39.9%), infection (27.4%), instability (7.5%), periprosthetic fracture (4.7%), and arthrofibrosis (4.5%). Similar to our study, they found that the most common reason for early failure (<2 years) was infection; however, their most common reason for later failure (>2 years) was aseptic loosening, while in our study it was instability.

Schroer et al [2] published a report on 844 patients who underwent revision knee arthroplasty from 6 high-level joint replacement centers over a 2-year period. The authors found the major reasons for failure to be aseptic loosening (31.2%), instability (18.7%), infection (16.2%), polyethylene wear (10%), arthrofibrosis (6.9%), and malalignment (6.6%). The mean time to revision surgery was 5.9 years, and nearly all (95%) of the TKAs had failed within 5 years of the index operation. Interestingly, their major reason for early failure (<2 years) was instability, while aseptic loosening was a major reason between 2 and 15 years after the index operation. The late failures (>15 years) were related primarily to polyethylene wear, followed by instability. These results suggest a distinction between early and late instability [14].

Kasahara et al [11] published their retrospective review on 140 revision TKAs done from 2006 to 2011 in a Japanese population. The authors reported the major reasons for revision to be aseptic loosening (40%), infection (24%), polyethylene wear/osteolysis (9%), and instability (9%). The authors attributed the dominance of aseptic loosening to their patients' active lifestyles, with no correlation to BMI in their revision group. Le et al [9] reviewed 253 revision TKAs over a 10-year period and found little difference between early failures (<2 years) that were due primarily to instability (26%), infection (24%), and stiffness (18%), and late failures (>2 years) that were similarly due to infection (25%), instability (18%), and stiffness (14%). Dalury et al [13] in a multicenter retrospective series of 820 revision TKAs found the major reasons for revision to be aseptic loosening (23.1%), infection (18.4%), polyethylene wear (18.1%), and instability (17.7%). Finally, Thiele et al [8] published a case series of 358 revision TKAs that occurred at 2 high-volume joint centers from 2005 to 2010. The most common reasons for revision were aseptic loosening (21.8%), instability (21.8%), malalignment (20.7%), and infection (14.5%). Furthermore, they found that time to revision correlated with reason for failure. Early failures (<1 year) were predominantly from infection, intermediate failures (1-3 years) were most commonly due to malalignment, and late failures (>3 years) were due to aseptic loosening.

Registry data are useful because it provides large volume of patients and demographic data that can be used to follow patients longitudinally. However, the problems of using national registry data are that they are limited by how the data are collected and further classified. It often lacks accuracy of diagnostic data due to the inflexibility of ICD-9 coding schemes. For example, Bozic et al [4] performed a study using the Nationwide Inpatient Sample that included 60,355 revision TKAs with the reasons for revision identified using the ICD-9-clinical modification diagnosis codes. The predominant causes for revision were infection (25.2%) and aseptic loosening (16.1%). However, this study was limited by small number of codes and inadequate documentation to represent the true reasons for failure, and roughly 15% of the revisions were coded for "other mechanical complications." Khan et al [15] published a current concept review based on worldwide National Joint Registries and found that the reasons for revision were aseptic loosening (29.8%), infection (14.8%), and pain (9.5%); the risk of failure of a primary TKA undergoing revision surgery at 10 years was 5%.

We found the major causes for revision TKA at our institution to be infection, instability, aseptic loosening, and stiffness. Overall, the failure rate with primary TKAs undergoing revision TKA was 2.2%. Our infection rate in this series was roughly 0.48%, which is below the published national average 0.92% [16]. Instability has multiple etiologies [14], but the fact that instability remains a dominant failure mode reinforces the continued attention to soft tissue balancing and component position as imperative for the long-term success of primary TKA. Instability being a major cause in our series is difficult to explain. The majority of our TKAs used PS implants and

Table 4
Reasons for Revision Surgery After Unilateral or Bilateral TKA.

Reason for Failure	Unilateral TKA (n = 347)	Bilateral TKA (n = 58)
Infection	88/25%	14/24%
Instability	80/23%	17/29%
Aseptic loosening	73/21%	13/22%
Stiffness	48/14%	8/14%
Periprosthetic fracture	11/3%	3/5%
Osteolysis/PE wear	10/3%	0
Malalignment	9/2.6%	1/1.7%
Isolated loose patella	6/1.7%	0
Pain	4/1.2%	1/1.7%
Polyethylene dissociation	4/1.2%	0
Metal allergy	2/0.6%	1/1.7%
Patellar AVN	2/0.6%	0
Peripatellar fibrosis/"clunk"	2/0.6%	0
Extensor mechanism failure	1/0.3%	0
Patellar malposition	1/0.3%	0
Patellar instability	1/0.3%	0

AVN, avascular necrosis; PE, polyethylene.

Table 5
Summary of Previous Literature.

	Number of Revisions	Average Time to Revision (mo)	Loosening	Infection	Instability	Periprosthetic Fracture	Arthrofibrosis/ Stiffness	PE Wear/ Osteolysis	Malalignment	Extensor Mechanism Deficiency	Patella AVN	Patellar Resurfacing	Patellofemoral Issues	Failure of Ingrowth	Implant Failure	Dislocation	Other	Conversion of UKA
Our study	405	26	21.50%	25.70%	24.40%	3.50%	14.10%	2.50%	2.50%	0.25%	0.50%	N/A	N/A	N/A	N/A	1%	N/A	N/A
Sharkey et al (2014) [10]	781	N/A	39.90%	27.40%	7.50%	4.70%	4.50%	0.00%	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sharkey et al (2002) [3]	203	44.4	24.10%	17.50%	21.20%	2.80%	14.60%	25.00%	11.80%	6.60%	4.20%	0.90%	N/A	N/A	N/A	N/A	N/A	N/A
Fehring et al (2001) [5]	279	N/A	3%	38%	27%	N/A	N/A	7%	N/A	N/A		N/A	8%	13%	N/A	N/A	5%	N/A
Schroer et al (2013) [2]	844	70.8	31.20%	16.20%	18.70%	3.20%	7%	10%	6.60%	1.20%	0.20%	4.10%	N/A	N/A	N/A	N/A	1.50%	N/A
Thiele et al (2015) [8]	358	48	21.80%	14.50%	21.80%	3.30%	4.50%	7%	20.70%	0.60%	N/A	5.90%	N/A	N/A	N/A	N/A	N/A	N/A
Kasahara et al (2013) [11]	140	N/A	40%	24%	9%	4%	N/A	9%	N/A	N/A	N/A	N/A	N/A	N/A	6%		8%	N/A
Bozic et al (2010) [4]	60,355	N/A	16.10%	25.20%	N/A	1.50%	N/A	8.10%	N/A	N/A	N/A	N/A	N/A	N/A	9.70%	7.10%	15.40%	N/A
Hossain et al (2010) [12]	349	84	14.90%	32.70%	7.70%	8.30%	2.60%	12.70%	6.60%	1.40%	N/A	N/A	N/A	N/A	0.80%	N/A	N/A	8%
Dalury et al (2013) [13]	820	N/A	23.10%	18.40%	17.70%	1.40%	9.30%	22.60%	2.90%	N/A	N/A	1.70%	N/A	N/A	N/A	N/A	2.9%	N/A

N/A, not applicable; UKA, unicompartmental knee arthroplasty; PE, polyethylene.

a measured resection technique with routine patellar resurfacing. Some data in the literature suggest that PS designed TKAs have higher revision rates than CR TKA designs [17], while other data suggest no differences between these 2 common design types [18,19].

Interestingly, a higher rate of failure was found for patients who had a CCK implant versus a PS implant, with a hazard ratio of 1.99. This may be due to those patients with CCK implants having poor bone stock, ligamentous deficiency, or large preoperative deformities. A large proportion of the CCK TKAs that failed in our series was a specific nonmodular CCK without stem extensions that may be predisposed to aseptic loosening of the femoral component [20]. Previous literature provided evidence that use of a second-generation CCK implant in primary TKA is safe in the short to medium follow-up period [21–23], but contradictory reports exist that in long-term follow-up, CCK implants have higher complication rates and decreased survival compared to standard TKAs, but again the majority of patients with a CCK primary TKA implant may have severe deformity or instability preoperatively [24]. While the decision to use a more constrained implant such as a CCK is always based on ability to obtain adequate soft tissue balance at the time of surgery, in our series using a CCK implant was a risk for revision surgery even after controlling for a variety of other factors. Our aseptic loosening rate of 0.4% with an average time to revision of 37 months is comparable to previously reported rates, where the cumulative incidence aseptic loosening rate was reported as 1.1% at 13 years postoperatively [25]. Aseptic loosening can be multifactorial influenced by patient, surgical technique, and implant design factors [26].

An elevated BMI has been debated as a risk factor for early tibia loosening [27,28]. In our study, patients who underwent revision TKA for aseptic loosening had an average BMI of 31; obesity was not a significant risk factor for failure, a result that differs from previous studies [22,23,29]. Instead, we found a fivefold increased risk of revision surgery in patients with a history of drug abuse. Bozic et al [30], in a Medicare database study, found a similar result with a hazard ratio of 2.1 for patients with drug abuse.

Patients with a primary diagnosis of deformity and mechanical ICD-9 codes had 3.5 hazard ratio compared to patients with primary OA ICD-9 codes. Berend et al [31], in a retrospective study of 8598 TKAs, found that a preoperative deformity $\geq 3°$ of varus on the tibia was a risk factor for medial bone collapse, while preoperative valgus deformity was associated with ligamentous imbalance and tibia component failure. Similarly, our patients with a post-traumatic and trauma preoperative diagnosis had a 1.8 hazard ratio compared to patients with OA preoperative diagnosis codes. Finally, we found that increasing age was protective for failure from TKA with a hazard ratio of 0.61. Previous studies found a similar trend with age and TKA failure [29,32]. For example, Vazquez-Vela Johnson et al [29] found that age below 60 years was the most significant factor associated with lower 10-year survival rate (82.4% vs 99.1%).

Finally, we found in our bivariate analysis that patients undergoing simultaneous bilateral TKAs had a larger proportion in the revised cohort compared to the nonrevised cohort (14% vs 11%, $P =$ .04; Table 2). However, in our multivariate analysis (Table 3), this finding did not reach significance. Previous literature is conflicting on complications and outcomes following simultaneous bilateral TKA. Several papers showed no differences in major complications between staged versus simultaneous bilateral TKA [33,34], while others showed that simultaneous bilateral TKA had lower readmission rates [35]. In a systematic review by Fu et al [36], simultaneous bilateral TKA had lower risk of deep infection and lower revision rates, but higher rates of mortality, pulmonary embolism, and blood transfusion. Bolognesi et al [37] in a Medicare study of 83, 441 patients found no differences in revision rate or infection;

the 3 major reasons for failures were instability (29%), infection (24%), and aseptic loosening (22%), which were similar to unilateral TKAs. We intend to investigate our bilateral TKA failure patients further to identify possible risk factors for simultaneous bilateral TKA failure.

Our study has several limitations. First, ours is a high-volume joint replacement center that may not be representative of the significant number of TKAs performed at low-volume community hospitals in the United States. According to Katz et al [38], 25% of TKAs performed in a Medicare population were done by surgeons who performed ≤12 TKAs annually and surgeons who performed ≥50 TKAs annually had fewer adverse events. A second limitation is that when the reason for failure could not be identified through operative reports and clinic notes, preoperative and postoperative radiographs, computed tomography scans, and magnetic resonance imagings were interpreted by the lead author and the senior author to determine the cause of failure. Although this was only done in 15 cases, some level of subjectivity and bias cannot be ignored. Third, although all our failures reported in this study had their index operations performed at our institution, we cannot account for patients who had revisions performed at outside institutions. We attempted to use a state-specific database to capture some of these patients but this was not possible. Therefore, our failure rate reported in this study likely underestimates the true failure rate. Another limitation is that in our study we defined failure as primary TKAs that went onto revision TKA, therefore this may not account for patients who have an unacceptable outcome and have not undergone a revision operation. Finally, multiple TKA designs from different manufacturers were used, which may not represent the trends in implant usage across the country.

Nonetheless, this is the largest study to our knowledge on reasons for TKA failures based on primary operations being performed at one institution, making our study free of referral bias that is present in previous published literature on total knee failures. Our findings add to the growing data that primary TKAs are no longer failing from polyethylene issues, but rather more commonly from infection and aseptic loosening. In the current practicing environment with the need to reduce overall healthcare costs and revision TKA [4], it is imperative to translate the data on reasons for revision to strategies for mitigating risk and therefore decreasing the overall cost and burden to the healthcare system.

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