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Why total knees fail-A modern perspective review

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arthroplasty (TKA) failures included aseptic loosening, instability and malalignment. As polyethylene production improved, modes of failure from polyethylene wear and subsequent osteolysis became less prevalent. Newer longitudinal studies report that infection has become the primary acute cause of failure with loosening and instability remaining as the overall greatest reasons for revision. Clinical database and worldwide national registries confirm these reports. With an increasing amount of TKA operations performed in the United States, and with focus on value-based healthcare, it is imperative to understand why total knees fail.

Key words: Total knee arthroplasty failure mechanism; Total knee arthroplasty failure mode; Revision total knee arthroplasty; Periprosthetic joint infection; Aseptic loosening total knee; Total knee arthroplasty instability

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Core tip: With increasing number of revision total knee arthroplasty (TKAs) being performed, tighter control on healthcare costs and value based care may occur. Surgeons are tasked with the responsibility to avoid risk factors for revision TKA. Newer longitudinal studies report that infection has become the primary acute cause of failure with loosening and instability remaining as the overall greatest reasons for revision. The surgeon must be aware of the risk factors and preventative measures for these failure modes, including preoperative management, surgical techniques and enhanced materials.

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Abstract

Historically, the most common mechanism of total knee

INTRODUCTION

With more total knee arthroplasty (TKA) operations

being performed and patients' lifespan increasing, there is an ever-growing number with this operation in the United States. Based upon 2010 data, an estimated 4.7 million individuals (3.0 million females, 1.7 million males) are living in the United States with a total knee. Additionally as the average age for TKA is becoming younger and living longer, the total number of revisions performed increases. By 2020, it is estimated 1.3 million TKAs will be performed along with 127000 revisions^[1]. Also, with focus on value-based healthcare, and government bundled payment initiatives, it is imperative to understand why total knees fail^[2].

HISTORICAL PERSPECTIVE

In 1982, Rand *et al*^[3] reported 227 knees undergoing revision in the Mayo Clinic registry data from 1970 to 1980. Within those revisions, average time from initial arthroplasty to failure was 2.7 years with loosening (34.9%) being the major cause for TKA failure. Instability and malalignment were second and third at 16.7% and 14.8%, respectively. Component malposition, periprosthetic fracture and patellofemoral complications were all around 5%. Periprosthetic joint infections were reported to be exceedingly rare at 0.2% (but this will become the leading cause of revision). The dominance of loosening was likely because of high use of the older hinge prosthesis designs such as the Guepar that resulted in increased interface stresses and loosening.

In 1988, Moreland described the etiology of total knee failures, and loosening and instability were still the leading causes with secondary reasons being infection, extensor mechanism disruption, arthrofibrosis, periprosthetic fracture and complex regional pain syndrome^[4]. Loose implants were caused by inappropriate bony resection, poor ligamentous balancing, cement technique, patient factors such as high activity level, implant constraint level, and osteolysis. Instability had the characteristics of varus/valgus malalignment, imbalance of the flexion-extension gap, anteroposterior laxity and patellofemoral subluxation/dislocation. Moreland concluded a majority of failure mechanisms is under the surgeon's technical control.

In 2001, Fehring *et al*^[5] reported early (< 5 year) failure mechanisms between 1986 and 1999. Their most common identified etiology for failure in 279 knees was now infection at 38%. Aseptic loosening of cemented implants had plummeted to 3% with lack of cementless TKA ingrowth at 13%, and polyethylene wear/osteolysis which causes loosening at 7%. Instability was still high at 26% with patellofemoral failures (usually instability) being 8%. Five percent had miscellaneous problems such as arthrofibrosis, malalignment, or periprosthetic fracture. They also concluded some of these causes could be improved by surgical technique and perioperative care. They proposed that infection prevention could be reduced by addressing wound healing problems (such as albumin > 3.5 g/L, preoperative total lymphocyte count (TLC) > 1500 cells/mm³, and transferrin level > 200),

reducing traffic in the operating room (OR), appropriate sterile technique and managing the operating room air environment. Their emphasis was that early failures could be controlled to improve implant longevity.

Sharkey *et al*^[6] won the 2002 Knee Society award paper for their review of TKA failures. They categorized their 212 TKA failures into early (< 2 years) and late (> 2 years). Early failures most commonly were infection in 25% of knees, instability (21%), arthrofibrosis (17%) and loosening (16%). Late failure groups were similar in numerical order to the overall cohort, reporting polyethylene wear (44%), loosening (34%) and instability (22%) as the major 3 causes. Overall, the most common failure mechanisms in decreasing order were estimated at 27% polyethylene wear, 25% component loosening, 21% instability and 17% infection. These authors also concluded that attention to surgical technique and postoperative care by the surgeon was very important but because multiple failure mechanisms were often seen in one case, some of the failure mechanisms could be addressed by design and material improvement.

In 2006, Mulhall *et al*^[7] reported on overall, early (< 2 years) and late (> 2 years) TKA failure mechanisms in 318 patients. Overall the majority of revisions were after 2 years and thus mechanical issues were primarily the cause. Early revisions (31% of patients) were primarily due to infection (25%), with ultimate outcomes worse than the outcomes of knees with revision for aseptic loosening. Revisions after 2 years (69% of their patients), were mechanical with instability (29%), polyethylene wear (25%) and component loosening (41%). They also concluded that patient factors such as diabetic control, and technical factors such implant design could be modifiable between early and late failures to improve patient outcomes.

The summary of these longitudinal studies is that infection has become the primary acute cause of failure with loosening and instability remaining as the overall greatest reasons for revision (Table 1). The researchers' conclusions are that most failures can be avoided by improvements in technique and design.

SHIFT TO NEWER POLYETHYLENE MANUFACTURING PROCESSES

Design improvement has impacted failure mechanisms. As polyethylene production improved, modes of failure from polyethylene wear and subsequent osteolysis became less prevalent. Hossain *et al*^[8] studied revisions of 349 knees between 1999 and 2008. Infection had become the most common reason for revision overall, both in early (< 2 years) and in late (> 2 years) failures. Aseptic loosening was second most common, followed by polyethylene wear.

Hossain *et al*^[8] and Schroer *et al*^[9] performed multi-center analysis of etiology for 844 revision TKAs between 2010 and 2011. They found aseptic loosening (31.2%), instability (18.7%) and infection (16.2%) as the 3 major overall causes with early failures continuing to

Table 1 Clinical studies by failure mechanism (%)

Ref.	Knees	Loosening	Infection	Instability	Malalignment	Poly/Lysis	Other
Rand <i>et al</i> ^[3]	227	34.9	0.2	16.7	14.8	-	5
Moreland <i>et al</i> ^[4]		MC		2 nd MC			
Fehring <i>et al</i> ^[5]	279	3%	38	26	5	7	5
Sharkey <i>et al</i> ^[6]	212	17/34	25/7.8	21/22	12/12	12/44	
Mulhall <i>et al</i> ^[7]	318	41	25/7	29	9	6/25	
Hossain <i>et al</i> ^[8]	349	3/12	12/21	4/3	4/3	1/12	
Schroer <i>et al</i> ^[9] and Lombardi <i>et al</i> ^[10]	844	19/31	23/16	25/19	8/7	1/10	2/1
Sharkey <i>et al</i> ^[11]	781	22/40	38/28	12/8	3/2	2/4	
Delanois <i>et al</i> ^[13]	337597	20.3	20.4	7.5		2.6	12
Kasahara <i>et al</i> ^[18]	147	40	24	9		9	18
Koh <i>et al</i> ^[19]	634	33	38	7	1	15	8

Overall percentages listed above may be approximates. Percentages may not be mutually exclusive^[6,8-10]. Sharkey *et al*^[6] table: First number is early (< 2 year) failures, second number is late failures; Hossain *et al*^[8]: First number is early (< 2 year) failures, second is late failures; Schroer and Lombardi *et al*^[9-10]: First number is early (< 2 year) failures, second is overall failures.

be infection (23%) and instability (25%). Secondary causes included polyethylene wear (10%), arthrofibrosis (6.9%) and malalignment (6.6%) with stiff knees being predominantly an early cause for revision among these. Polyethylene wear represented less than 1% of revisions performed under 5 years, but remained common in revision failures greater than 15 years in knees with older polyethylene which confirmed benefit of newer polyethylene improvements. Aseptic loosening was the only failure mechanism consistent in all time intervals^[10].

Sharkey *et al*^[11] provided a 10-year update on their experience of performing 781 revisions of 10,003 total procedures (7.8% revision rate). They too saw a dramatic decrease from 25% to 3.5% in the rate of polyethylene wear as the cause of revision. Early (< 2 years) failures were 37.6% of all failures with infection most common, and more than half (51.4%) of the 62.4% late (> 2 years) revisions were aseptic loosening.

CLINICAL DATA VS LARGE DATA

While most published results of total knee revisions came from single-center or regional multi-center data, larger and more diverse cohorts have become possible with the advent of nationwide databases. In the United States, the Nationwide Inpatient Sample (NIS) database, developed in 1988 and revamped in 2012, provides a random sampling of approximately 20% of all United States hospital discharges and encompasses smaller community hospitals as well as larger urban academic centers. Using this registry, Bozic *et al*^[12] reported on 60355 TKA revision procedures performed between 2005 and 2006 across the United States. They found the most common cause of revision knee arthroplasty was infection at 25.2%, implant loosening at 16.1%, and implant failure or breakage at 9.7%. While noting the limitations of large administrative data, they reported their findings were similar to other studies that found infection to be the greatest contributing factor to at least early failure mechanisms.

Delanois *et al*^[13] provided an updated look at the revision rate in the United States using the same NIS database from 2009 through 2013 and reaffirmed that the two leading causes of revision TKA were infection and aseptic loosening at 20.4% and 20.3%, respectively. Both NIS-based papers reported on higher revision rates in the South with upwards of one-third of all revision performed in southern states. Although demographic data was provided, with well over 70% of all revision occurring in Caucasians, no analysis was performed to identify regional differences in failure mechanisms. All-component revision was the most common operation with a total healthcare cost averaging more than \$75000.

WORLD EXPERIENCES

The use of nationwide registries began in 1975 with the Swedish Knee Arthroplasty Register (SKAR) through the efforts of Goran Bauer^[14]. Since then, other countries have followed their example, including Finland (1980), Norway (1987), Denmark (1995), South Korea (1989), New Zealand (1998), England and Wales (2003), and Japan (2010) (Table 2).

The initial success of the registries prompted the creation of the Nordic Arthroplasty Register Association, a compilation of arthroplasty databases from Sweden, Denmark, and Norway who shared similar demographics, healthcare and socioeconomic systems, and were in close proximity to each other. Subsequently Niimaki in 2015 combined five worldwide registries: Australia, New Zealand, Norway, Sweden, and England and Wales^[15]. The leading indication for revision in each country was aseptic loosening (range 22.8%-29.7%). Pain was the second leading indication for revision in Norway and New Zealand (27.4% and 22.0% respectively), while infection was the second most common cause in the three remaining countries (20.6%-21.7%). However, Niimaki identifies inconsistencies in the categorization of failure mechanisms amongst the registries that clouds the ability to interpret the results. For example, pain and malalignment are not categories in the Swedish

Table 2 Large data and registry data by total knee arthroplasty failure mechanism

Ref.	Knees	Loosening, %	Infection, %	Instability, %	Poly/Lysis, %	Other, %
Bozic <i>et al</i> ^[12]	60435	16	25	7	8	
Delanois <i>et al</i> ^[13]	337597	20.3	20.4	7.5	2.6	12
Sadoghi <i>et al</i> ^[23]	36307	30	15	6	8	
Australia 2003-2012 ^[24]	31698	30	22	6	2	
England/Wales 2011-2012 ^[25]	5135	35	23	14	20	
New Zealand 1999-2011 ^[26]	4603	37	24	7	n/a	
Norway 1994-2009 ^[27]	3445	24	13	10	5	
Sweden 2001-2010 ^[28]	3375	26	23	13	5	

Overall percentages are listed above.

registry whereas polyethylene wear is not an option in the United Kingdom registry. He therefore suggests that standardizing the registries can help in compiling data to draw more compelling conclusions. Nevertheless, the data consistently supports aseptic loosening as the most common indication for revision TKA at similar rates to those found in the United States. Siqueira *et al*^[16] reviewed TKA failure modes outside the United States by combining both large clinical studies and national joint registry results. They concluded 1994-2012 national databases and reported aseptic loosening as the most common reason for failure, with infection being second.. Clinical studies reported by large tertiary referral centers also reported aseptic loosening as being the most common overall reason for revision, while early failures were due to infection. The data from Europe, although not consistently reported, confirms that the emphasis on failure needs to be focused on infection early and overall on aseptic loosening.

The performance of TKA is quickly rising in Asia, where over half the world's population resides, and it is especially prevalent in women, who have an 8-fold increased rate of primary TKAs compared to men^[17]. Kasahara *et al*^[18] recently reported on a multicenter experience of five arthroplasty referral centers in Japan with 140 TKA revision from 2006-2011. Overall revision rate was 3.3% with aseptic loosening as the leading cause at 40% followed by infection at 24%. Koh *et al*^[19] from South Korea, published a retrospective review of 634 revisions at 19 centers from 2008-2012, representing an estimated 10% of all procedures performed in the country. Overall revision rate was 3.0% with infection (38%) as the leading cause followed by aseptic loosening (33%) and wear (13%). Similar to other reports, they separated failures as early (< 2 years) versus late (> 2 years); infection dominated as the leading cause of early failure (77%) but it was only 23% of all late failures with aseptic loosening (44%) the most common as it is throughout the world. Wear was only an indication for revision in the late failure group and comprised 18%. With limited long-term registry data, it remains unclear whether the failure patterns of knee replacement differ between the Western and Eastern Hemispheres, but it seems that Asia is more similar to the United States with infection the early

cause while Aseptic loosening dominates all time periods in Europe.

CURRENT CHALLENGES

As total knee arthroplasty increases in demand and prevalence, the number of revision total knee operations increase as well. Kurtz *et al*^[2] predicted the number of revision TKAs performed in the United States by 2030 would be greater than 250000 operations. Hamilton *et al*^[20] reviewed risk factors for revision TKA which includes obesity, young age and comorbid conditions as the most common in both the United States as well as other countries.

Altogether, patients across the world with total knee arthroplasties face similar challenges today. Aseptic loosening/instability and infection are the primary causes of failure. Countries with higher rates of unicompartmental or bicompartmental arthroplasties increasingly cite pain as an indication for revision, though that remains highly dependent on the patient, the surgeon, and the reporting mechanism. As surgical implants continue to evolve, surgical techniques to achieve long-term fixation and careful attention to infection prevention remain the most challenging obstacles to achieve excellent long-term outcomes.

As the understanding of how total knees fail, orthopedic research has focused on improving the technology and surgical technique as well as in depth study of infection. There is a large volume of research dedicated towards lowering infection risk factors such as patient optimization, efficient surgery, maintaining ideal intraoperative conditions, and decreasing postoperative complications^[21]. Surgical technique has focused on understanding patient anatomy, and personalizing leg alignment and component position. Bellemans *et al*^[22] evaluated anatomic and mechanical axis in 250 asymptomatic adults. They reported that 32% of males and 17% of females had a natural mechanical axis of 3 degrees varus or greater. A common etiology of instability is malrotation of the femoral component relative to the tibia. Meticulous attention to surgical technique is critical as instrumentation is unable to adjust for this rotation. Personalization of a patient's normal anatomy and ligament balancing may be helpful to lower revision rates

and patient satisfaction.

CONCLUSION

With increasing number of revision TKAs being performed, tighter control on healthcare costs and value based care may occur. Surgeons are tasked with the responsibility to avoid risk factors for revision TKA. Newer longitudinal studies report that infection has become the primary acute cause of failure with loosening and instability remaining as the overall greatest reasons for revision. Knowledge of total knee arthroplasty failure mechanisms allows the arthroplasty surgeon to be aware of individual risk factors, and to strategize management for each patient to optimize their care.

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