# Current Failure Mechanisms After Knee Arthroplasty Have Changed: Polyethylene Wear Is Less Common in Revision Surgery

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**Background:** The present study was designed to clarify which underlying indications can be currently considered the main reasons for failure after total knee arthroplasty as a function of time.

**Methods:** We conducted a retrospective study that included all first revisions of total knee replacements during 2005 to 2010 at two high-volume arthroplasty centers. A revision was defined as the replacement of at least one prosthetic component. In the descriptive analysis, polyethylene wear, aseptic loosening, periprosthetic infection, malalignment, instability, arthrofibrosis, extensor mechanism deficiency, periprosthetic fracture, and retropatellar arthritis were given as the failure mechanism associated with an early, intermediate, or late time interval (less than one year, one to three years, and more than three years, respectively) after the index total knee arthroplasty.

**Results:** Three hundred and fifty-eight revision total knee arthroplasties were included. Of those revisions, 19.8% were performed within the first year after the index arthroplasty. The most common indications for revision, besides aseptic loosening (21.8%), were instability (21.8%), malalignment (20.7%), and periprosthetic infection (14.5%). Revisions due to polyethylene wear (7%) rarely occurred. In the early failure group, the primary causes of revision were periprosthetic infection (26.8%) and instability (23.9%). In the intermediate group, instability (23.3%) and malalignment (29.4%) required revision surgery, whereas late failure mechanisms were aseptic loosening (34.7%), instability (18.5%), and polyethylene wear (18.5%).

**Conclusions:** Aseptic loosening, instability, malalignment, and periprosthetic infection continue to be the primary failure mechanisms leading to revision surgery. Contrary to previous literature, the results in the present study showed a substantial reduction in implant-associated revisions such as those due to polyethylene wear. Failure mechanisms that occur persistently early and in the intermediate term, such as periprosthetic infection, instability, and malalignment, remain common causes of revision surgery.

**Level of Evidence:** Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

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Total knee arthroplasty is the treatment of choice for patients with an advanced degenerative joint disorder. Epidemiological data underline the importance of this procedure, with more than 650,000 total knee arthroplasties performed in the United States in 2010 and 134,000 in Germany in 2012[1-3]. Despite continuing technical innovation and a new understanding of biomechanics, a substantial decline in revision rates has not occurred over the last decade. A comparison of quality reports and national prosthetic joint registers revealed a 12% to 12.8% revision rate, with 78,600 revisions in

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the U.S. in 2010 and 17,200 in Germany in 2012[1,2]. In fact, independent quality reports[2-4] in Germany showed an increase in the revision rate of approximately 5% to 6% from 2001 to 2012.

Previous reports have analyzed failure mechanisms after total knee arthroplasties performed between 1986 and 2000[5-7]. According to those results, polyethylene wear was most often identified as one of the major reasons for revision surgery[5,6]. Periprosthetic infection was the most common cause of early revision[5,6,8].

On the basis of the available historical data, an up-to-date analysis of the current causes of revision was necessary so that potential improvements in primary arthroplasty over the last ten years could be identified. The main question was whether the reasons for revision total knee arthroplasty had changed during contemporary practice. In view of recent innovations in material properties and prosthetic design, we hypothesized that there would be a reduction in the cases of prosthetic loosening due to wear. On the contrary, we expected an elevated rate of revisions due to periprosthetic infection because detection rates are higher with modern diagnostic techniques. As a result of the improved understanding of component malalignment as it relates to poor function, we assumed an increased rate of revisions for this reason as well. The present study, therefore, investigated the failure modes for revision surgery as a function of implant age at two separate arthroplasty centers in Germany.

## Materials and Methods

A revision was defined as the replacement of at least one prosthetic component. Only first revisions were included. Exclusion criteria were a repeat revision total knee arthroplasty, failed unicondylar prostheses, and debridement procedures with retention of the components (except arthroscopic arthrolysis). The surgeon performing the revision surgery determined the reason for failure. The failure categories were polyethylene wear, aseptic loosening, instability, periprosthetic infection, arthrofibrosis, malalignment, extensor mechanism insufficiency, periprosthetic fracture, and progressive retropatellar arthritis. If failure was due to multiple reasons, the dominant cause was used for the subsequent analysis. The primary failure mechanism was established using the criteria described below. The diagnosis of aseptic loosening served as a secondary diagnosis if another failure mechanism was determined.

Periprosthetic infection was regarded solely as a primary diagnosis and was based on the criteria defined by the Musculoskeletal Infection Society and the American Academy of Orthopaedic Surgeons (AAOS)[9-11]. A revision involving two stages or more because of infection was considered one event and was counted as a single operation.

The diagnosis of polyethylene wear was established on the basis of macroscopic and microscopic findings, according to type I of the classification system described by Krenn et al.[9], and served as a primary diagnosis only in these patients.

Failures were assigned to the instability group in the event of a positive clinical history on the basis of symptomatology, including a sense of knee instability with or without frank giving-way, recurrent knee swelling, and instability that was worse on descending stairs. An objective assessment was made according to the results of the physical examination that included evaluation of the limb alignment in a standing position and observation of the gait, the varus-valgus and anteroposterior stability at full extension and flexion and at 30° and 90° of flexion, and the drawer test[12,13].

Malpositioning and malrotation were assessed radiographically (anteroposterior, lateral, tangential, and full-length standing radiographs) and with computed tomography (CT). Full-length standing radiographs were used to rule out mechanical axis malalignment. Patients with patellar maltracking and negative findings on a routine workup, including the elimination of periprosthetic infection and aseptic loosening, underwent CT scanning[14]. Rotation was measured using a standardized protocol modified by Berger et al.[15]. On the basis of academic studies by Nicoll and Rowley[16], Pietsch and Hofmann[17], and Bhattee et al.[18], an external or internal rotation of the femoral components of >10° or >5°, respectively, was regarded as a pathological component rotation. In relation to the tibial components, an internal rotation of <18° was considered normal and higher degrees of rotation were deemed pathological[14,16,18,19]. Component malpositioning was defined as symptomatic coronal plane malalignment of >5°, anterior slope (<0°), or excessive posterior slope (>10°). For patients with stiffness after total knee arthroplasty, only those with primary arthrofibrosis without evidence of another pathomechanism were categorized as having failure due to arthrofibrosis. Secondary arthrofibrosis was categorized according to its primary etiology. Revision involving isolated resurfacing of the patella, when performed, was categorized as a failure due to retropatellar arthritis only if the patient reported retropatellar knee pain, especially in flexion, with pathological findings on a series of tangential radiographs of the patella.

This retrospective study included all first revisions of total knee arthroplasties during 2005 to 2010 at two high-volume arthroplasty centers (one was a university academic center and one was a nonuniversity academic center). Approximately 80% of the patients had had the primary total knee arthroplasty at other institutions and were referred to our arthroplasty revision centers. Relevant medical information was obtained through a standardized spreadsheet and electronic medical record system. In the absence of a consistent, generally accepted categorization for early and late failure in the literature (two versus five-year cutoff), we subdivided the observed time interval into three groups: less than one year (early failure), one to three years (intermediate failure), and more than three years (late failure) after the index procedure. The rationale for this classification was to point out the detailed distribution of failure mechanisms shortly after the index operation. Studies have emphasized a relationship between the time to failure and the cause, with attention paid to the first postoperative years, which are often referred to as the vulnerable phase[20,21].

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## Results

Three hundred and fifty-eight patients met the inclusion criteria and were evaluated. The mean age of the total cohort

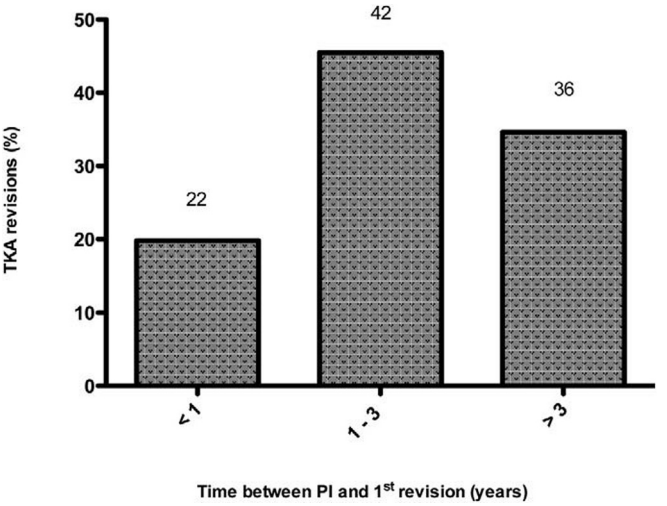


Fig. 1

Total knee arthroplasty (TKA) revisions in relation to the observed time interval. PI = primary implantation.

**TABLE I Summary of Study Results**

| Failure Mechanism | Total *(No. [%])* (N = 358) | Time to Revision* *(yr)* | Time to Failure† *(No. [%])* | | |
|---|---|---|---|---|---|
| | | | Early (N = 71) | Intermediate (N = 163) | Late (N = 124) |
| Polyethylene wear | 25 (7.0) | 11 ± 3.9 (1-16) | 0 (0) | 2 (1.2) | 23 (18.5) |
| Aseptic loosening | 78 (21.8) | 5 ± 4.5 (0-20) | 9 (12.7) | 26 (16.0) | 43 (34.7) |
| Instability | 78 (21.8) | 3 ± 3.5 (0-19) | 17 (23.9) | 38 (23.3) | 23 (18.5) |
| Periprosthetic infection | 52 (14.5) | 1.5 ± 3.3 (0-15) | 19 (26.8) | 22 (13.5) | 11 (8.9) |
| Arthrofibrosis | 16 (4.5) | 1.5 ± 2.1 (0-7) | 5 (7) | 8 (4.9) | 3 (2.4) |
| Malalignment | 74 (20.7) | 2 ± 1.7 (0-8) | 13 (18.3) | 48 (29.4) | 13 (10.5) |
| Extensor mechanism deficiency | 2 (0.6) | 1 | 0 (0) | 2 (1.2) | 0 (0) |
| Periprosthetic fracture | 12 (3.3) | 2.5 ± 5 (0-17) | 3 (4.2) | 5 (3.1) | 4 (3.2) |
| Retropatellar arthritis | 21 (5.9) | 2.0 ± 1.7 (0-7) | 5 (7.0) | 12 (7.4) | 4 (3.2) |

*The values are given as the mean and the standard deviation, with the range in parentheses. †Early failure was defined as failures that occurred less than one year postoperatively; intermediate, between the first and third year; and late, at three years or later.

at the time of revision was 69.3 years (range, twenty-three to ninety-two years). More female (65%) than male patients underwent revision surgery. The mean body mass index was 28.7 kg/m$^2$ (range, 15.9 to 49.6 kg/m$^2$).

The highest failure rate was seen within the first six years after the index operation (77.9% of the total patient cohort). Of the patients included in the present study, 19.8% required the revision within the first year after the primary procedure. The second procedure was done between one and three years after the index operation in 45.5% of our patient cohort and at more than three years after the primary implantation in 34.6% of our patients (Fig. 1). Among the patients who had a revision, 91% had had the index arthroplasty done within the previous ten years. The median interval between primary implantation and revision was four years (range, zero to twenty years). The mean time to revision was 1.5 years in the early and intermediate failure groups and 7.9 years in the late failure group. In nearly all patients, a complete component exchange was performed.

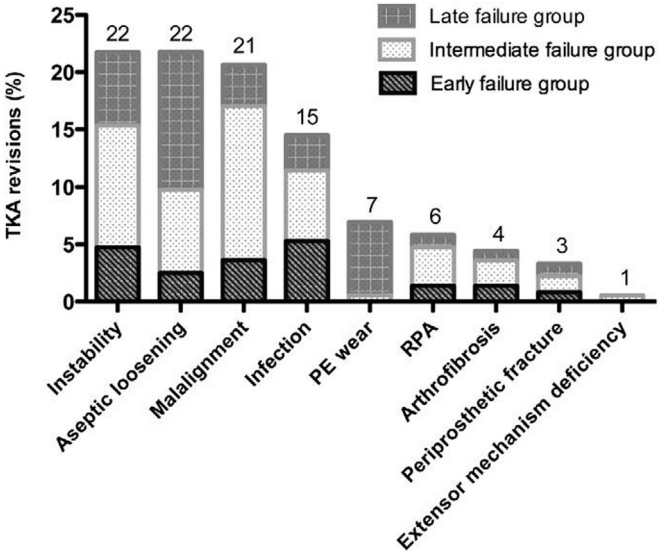


Fig. 2
The percentage of revisions as a function of failure mechanism and failure period. TKA = total knee arthroplasty, PE = polyethylene, and RPA = retropatellar arthritis.

The most common indications for revision, besides aseptic loosening (21.8%), were instability (21.8%), malalignment (20.7%), and periprosthetic infection (14.5%). In the first year after the index operation, the primary cause of revision was periprosthetic infection (26.8%), followed by instability (23.9%) and malalignment (18.3%). Besides ligament instability (23.3%) and aseptic loosening (16%), malalignment (29.4%) was again a principal cause of revision at one to three years after primary implantation. Implant lifespans of over three years were associated with revision due to aseptic loosening (34.7%) or ligament instability (18.5%) and polyethylene wear (18.5%). With regard to early and intermediate revisions, polyethylene wear (1.2%) was a minor cause of failure (see Appendix). Of the late revisions, 8.9% were performed because of periprosthetic infection. Arthrofibrosis was a rare occurrence in the total cohort. Only 7% of the revisions within one year after implantation were arthroscopic or open arthrolysis procedures; 4.9%, in the intermediate failure period (one to three years after surgery); and 2.4%, after the third year. Rare causes of a subsequent procedure included extensor mechanism insufficiency (0.6%), periprosthetic fracture (3.3%), and progressive retropatellar arthritis (5.9%) (Fig. 2, Table I).

## Discussion

The decreased proportion of polyethylene-related failures (7% overall), which mainly occurred more than three years postoperatively (18.5% of 124 late failures), supported our hypothesis that revisions for prosthetic loosening resulting from wear would be reduced. We expected an increased revision rate

**TABLE II Cohort Description Before and on or After January 1, 2000**

| | Group That Had Index Surgery Before 2000* | Group That Had Index Surgery in or After 2000* |
|---|---|---|
| No. *(%)* of patients | 58 (16) | 300 (84) |
| Mean age (range) *(yr)* | | |
| Index surgery | 64 (37-78) | 65 (23-91) |
| Revision surgery | 75 (46-89) | 68 (23-92) |
| Failure modes *(%)* | | |
| Polyethylene wear | 31.6 | 2.4 |
| Instability | 10.5 | 24.3 |
| Aseptic loosening | 38.6 | 18.8 |
| Periprosthetic infection | 10.5 | 14.6 |
| Malalignment | 1.8 | 25.3 |

*The most commonly used implants were the Natural-Knee System (Zimmer), AGC (Biomet), and Duracon (Stryker) in the group that had the index procedure before 2000, and the LCS (low contact stress; DePuy), NexGen (Zimmer), and PFC Sigma (DePuy) in the group that had the index surgery in or after 2000.

for periprosthetic infection because of modern diagnostic techniques. We found a surprisingly high frequency of early deep periprosthetic infections as a failure mode within the first postoperative year (26.8%). We also predicted an increased rate of revisions caused by inadequate component alignment (20.7%), which was confirmed in this study.

The study has several limitations. First, a substantial number of the index procedures were referrals with incomplete baseline information because of the lack of a central registry in Germany. Additionally, we observed a wide range of time that had passed between the index procedure and the revision in the study cohort. For 83.8% of all primary implantations, the index operations took place within a recent time frame (2000 to 2010), with an almost consistent use of implant designs (Table II). Nevertheless, we cannot exclude the systematic impact made by multiple prosthetic designs and the development of surgical techniques. Second, the classification of the failures, which was done by the surgeon, was not evaluated with regard to consistency. Each surgeon agreed to use the same diagnostic categories, and we attempted to establish clear criteria for categorization. Third, long-term changes (more than twenty years) could not be analyzed in detail and may impact our results in the future (e.g., polyethylene wear).

**TABLE III Comparison of Previous Reports and the Present Study on Failure Mechanisms After Total Knee Arthroplasty***

| Study | No. of Patients | Time Frame for Revision Surgery | Mean Time to Failure (Range) | Time to Revision by Intervals Analyzed *(yr)* | Aseptic Loosening *(%)* | Instability *(%)* | Periprosthetic Infection *(%)* | Malalignment *(%)* | Polyethylene Wear *(%)* |
|---|---|---|---|---|---|---|---|---|---|
| Fehring et al.[7]† (2001) | 279 | 1986-1999 | <5 yr | <5 | 26 | 26 | 38 | NR | 7 |
| Sharkey et al.[6] (2002) | 203 | 1997-2000 | NR (1.1 to 28 yr) | <2/≥2 | 24 | 21 | 18 | 12 | 25 |
| Mulhall et al.[5]‡ (2006) | 318 | NR | 7.9 yr (0.6 to 27 yr) | <2/≥2 | 41 | 30 | 10 | 9 | 25 |
| Dalury et al.[22] (2013) | 693 | 2000-2011 | 6 yr (0.1 to 26 yr) | <5/≥5 | 23 | 18 | 18 | 3 | 18 |
| Schroer et al.[20] (2013) | 844 | 2010-2011 | 5.9 yr (10 d to 31 yr) | <2/2-5/5-15/>15 | 31 | 19 | 16 | 6 | 10 |
| Present study | 358 | 2005-2010 | 4.03 yr (0 to 20 yr) | <1/1-3/>3 | 22 | 22 | 15 | 21 | 7 |

*NR = not reported. †Only early revision. ‡In Mulhall et al., the percentages totaled >100% because some knees had more than one mode of failure recorded.

This study is based on an analysis of 358 knee replacements, 77.9% of which were revised within six years after the index operation. In 2001, as part of an analysis of 279 revision total knee arthroplasties, Fehring et al. reported that as many as 64% of the patients underwent the revision within five years after the index operation[7]. In 2002, Sharkey et al. observed a mean interval between primary and secondary procedures of 1.1 years in the early failure group (less than two years postoperatively) and seven years in the late failure group (more than two years)[6]. Of the total cohort, 55.6% underwent the revision within two years after the initial surgery. Mulhall et al., in a 2006 study of 318 patients who had revision total knee replacement, reported a median interval of 7.9 years from the primary total knee arthroplasty to the time of failure, with a 31% proportion of early failure (less than two years)[5]. Despite differences in study design, all studies (including our own results) indicated a consistently high proportion of revisions within the first five years. Even recent studies by Schroer et al.[20] and Dalury et al.[22], with a different observed time frame, confirmed these results (Table III). The first postoperative year was not considered explicitly in these comparative studies. Our follow-up revealed that a substantial proportion of patients with a revision (19.8%) had the revision in the first postoperative year.

However, the reasons for revision identified in the present study differ from those reported by Sharkey et al.[6] more than ten years ago, when the most prevalent mechanism of failure was polyethylene wear. Our study identified aseptic loosening, instability, infection, and malalignment as leading failure mechanisms, irrespective of the time interval considered.

Deficient rotational adjustment, especially of the femoral component, has been identified in recent years with the aid of CT as a particularly important pathology. This is highlighted by the findings in the present study, which indicate that a high percentage of patients have prosthetic malalignment (20.7%) compared with that noted in previous reports (2.8% to 11.8%)[17,19]. Prior studies that have addressed the issue of knee failure mechanisms did not identify the number of patients undergoing CT scans. The working groups led by Lakstein et al.[19] and Pietsch and Hofmann[17] demonstrated the differential diagnostic relevance of pain of unknown etiology following total knee arthroplasty. They observed a marked reduction in symptoms following surgical adjustment of rotation and reported benefits following early revision for rotational malalignment.

Ligament instability, which continues to be a leading cause of revision, illustrates the relevance of soft-tissue balancing and the use of an appropriate implant design based on the primary knee pathology during the index surgery[23]. In our patient cohort, an unstable total knee replacement was the primary cause of revision between one and three years and ranked among the leading failure mechanisms during the first year after the index operation. In an age in which priority is given to treatment with a highly functional but unforgiving surface design, correct surgical technique is gaining in importance. Song et al. observed a relationship between the time to manifestation of instability symptoms and the causes of instability[21]. Related technical errors, such as a flexion-extension gap mismatch or component malpositioning, tended to present earlier than isolated ligament insufficiency (2.8 versus 4.2 years) for various reasons[21].

The comparatively low overall proportion of wear-induced osteolysis requiring revision (7%), with its main occurrence more than three years after the index surgery (18.5%), in the present study is in marked contrast to previous reports, which have indicated that this cause was responsible for 25% of total knee arthroplasty revisions[5,6]. Without confirming the original polyethylene type in the index surgery, we can only assume that the different rates of wear-related failures were due to improvements in polyethylene manufacturing and material properties. Among various advancements, the migration from gamma sterilization in air to gamma sterilization in an inert environment is likely the key[24,25]. However, if patients who had had the primary arthroplasty done before 2000 had been excluded, we would not have a homogeneous patient group. Thus, for this analysis, we set an arbitrary boundary (before January 1, 2000 or on or after that date), only on the basis of historical knowledge and ignoring the continuous process of technical development (Table II).

Our study also found periprosthetic infection to be the fourth most common cause of revision (14.5%), comparable with the findings reported by Sharkey et al.[6]. We noted a high incidence of periprosthetic infections in the first postoperative year (26.8% of revisions). Similar results in previous reports, in which early infections were categorized as those occurring less than two years postoperatively, showed that infection was one of the most common mechanisms of early failure[6,20]. With the introduction of the so-called gold-standard definition of periprosthetic joint infection by the workgroup of the Musculoskeletal Infection Society[10,11], new diagnostic tools such as the classification system described by Krenn et al.[9], and new detection methods[26] (e.g., sonication), the diagnosis of periprosthetic infections has been clarified. Infections that occur early are most likely the result of the operating-room environment, intraoperative contamination, or immediate postoperative wound complications[27] and can probably be reduced by addressing patient and surgeon-related risk factors.

In summary, aseptic loosening, instability, malalignment, and periprosthetic infection continue to be the primary failure mechanisms leading to revision surgery. Previous studies have demonstrated a disproportionate number of implant-associated failure mechanisms (polyethylene wear and osteolysis)[5,6]. The results of the present study and recently published analyses have shown a substantial reduction in implant-associated revisions, such as those related to polyethylene wear, because of improvements in implant performance and polyethylene manufacturing[24,25]. Nevertheless, periprosthetic infections, instability, malalignment, and aseptic loosening are still the main causes of revision surgery and are surgeon-related factors.

## Appendix

eA Figures showing the cumulative rate of revisions due to specific failure mechanisms and the relation of failure modes for polyethylene wear, aseptic loosening, instability,

malalignment, and periprosthetic infection to the time to revision are available with the online version of this article as a data supplement at jbjs.org. ■

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