Outcome of Revision Surgery for Infection After Total Knee Arthroplasty

Results of 3 Surgical Strategies

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Abstract

Background: Periprosthetic joint infection (PJI) after knee arthroplasty surgery remains a serious complication, yet there is no international consensus regarding the surgical treatment of PJI. This study aimed to assess prosthesis survival rates, risk of revision, and mortality rate following different surgical strategies (1-stage versus 2-stage implant revision and irrigation and debridement with implant retention) that are used to treat PJI.

Methods: The study was based on 644 total knee arthroplasties (TKAs) that were revised because of a deep infection (i.e., surgically treated PJI) and reported to the Norwegian Arthroplasty Register (NAR) from 1994 to 2016. Kaplan-Meier and multiple Cox regression analyses were performed to assess implant survival rate and risk of revision. We also studied mortality rates at 90 days and 1 year after revision for PJI.

Results: During the follow-up period, 19% of the irrigation and debridement cases, 14% of the 1-stage revision cases, and 12% of the 2-stage revision cases underwent a subsequent revision because of a PJI. The 5-year Kaplan-Meier survival rate with revision for infection as the end point was 79% after irrigation and debridement, 87% after 1-stage revision, and 87% after 2-stage revision. There were no significant differences between 1-stage and 2-stage revisions with subsequent revision for any reason as the end point (relative risk [RR], 1.7; 95% confidence interval [CI], 0.9 to 3.5) and no difference with revision because of infection as the end point (RR, 1.6; 95% CI, 0.7 to 3.7). In an age-stratified analysis, however, the risk of revision for any reason was 4 times greater after 1-stage revision than after 2-stage revision in patients over the age of 70 years (RR, 4.3; 95% CI, 1.3 to 14.8). Age had no significant effect on the risk of subsequent revision for knees that had been revised with the irrigation and debridement procedure. The 90-day and 1-year mortality rates after revision for PJI were 1.2% and 2.5%, respectively.

Conclusions: Irrigation and debridement yielded good results compared with previous published studies. Although the 1-stage revisions resulted in a fourfold increase in risk of subsequent revision compared with the 2-stage revisions in older patients, the overall outcomes after 1-stage and 2-stage revisions were similar.

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

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Periprosthetic joint infection (PJI) is one of the most serious and devastating complications following knee arthroplasty. PJI can result in greatly decreased functioning and quality of life and, in the worst cases, permanent arthrodesis, amputation, or even death[1]. The cumulative rates of PJI at 1 year after primary knee arthroplasty range from 0.5% to 5% depending on the patient's risk factors[2-5]. Although PJI rates following arthroplasty are low, the number of revision arthroplasties due to PJI is rising because of an increasing number of primary knee arthroplasty patients[6]. PJI is the leading cause of revision surgery, accounting for >15% of all revisions[7,8], and PJI is the dominant cause of revision during the first 4 years after primary surgery[9]. In Norway, 1% of primary knee arthroplasties that were performed between 1994 and 2015 were revised at least once because of a PJI[7,10]. According to the Norwegian Arthroplasty Register (NAR) 2016 Annual Report, around 20% of all primary revisions between 1994 and 2015 were performed because of PJI[10]. According to Furnes, 37% (10 of 27) of secondary revisions in Norway between 1994 and 2004 were due to PJI[11]. However, the optimal treatment strategy for PJI remains controversial[12-14].

Treatment of PJI usually consists of a combination of surgery and long-term therapy with antibiotics. Irrigation and debridement with retention of the prosthesis or exchange of the prosthesis in 1 or 2 stages are surgical procedures that frequently are used to treat PJI. In certain cases, an arthrodesis or an amputation is required to eradicate the infection. For chronic cases, the 2-stage revision strategy with a temporary antibiotic-impregnated cement spacer seems to be the most frequently used method[13-16]. However, this strategy requires a minimum of 2 extensive surgical procedures and is associated with long periods of hospitalization, functional impairment, and high health-care costs compared with a 1-stage revision. Therefore, some surgeons believe that an exchange of the implant in 1 procedure is preferable, but 1-stage revisions are still less common than 2-stage revisions[13,17]. However, the 1-stage revision has become standard treatment for deep infection in some specialized European centers[2,18]. Compared with revision procedures involving an exchange of the implant, irrigation and debridement is less extensive, with presumably lower morbidity. However, reported success rates following this procedure vary from very poor (37%)[19] to quite good (75%)[20].

Limited information exists on longer-term results of revision knee arthroplasties in infected cases, and most series have relatively few cases and focus on only 1 treatment strategy. Thus, based on NAR data, we primarily aimed to assess the survival rate, the risk of a second revision, and the mortality rate following revision knee arthroplasty because of deep infection with 3 different surgical procedures: irrigation and debridement with implant retention, 1-stage revision, and 2-stage revision. Secondarily, we aimed to compare the outcomes of 1-stage and 2-stage revision procedures.

Materials and Methods

Study Population and Source of Data

This study was based on data from the NAR. Between 1994 and 2016, 61,395 primary total knee arthroplasties (TKAs) without a patellar component were reported to the NAR. Of these, 653 (1.1%) had been revised because of deep infection (i.e., surgically treated PJI). To make the

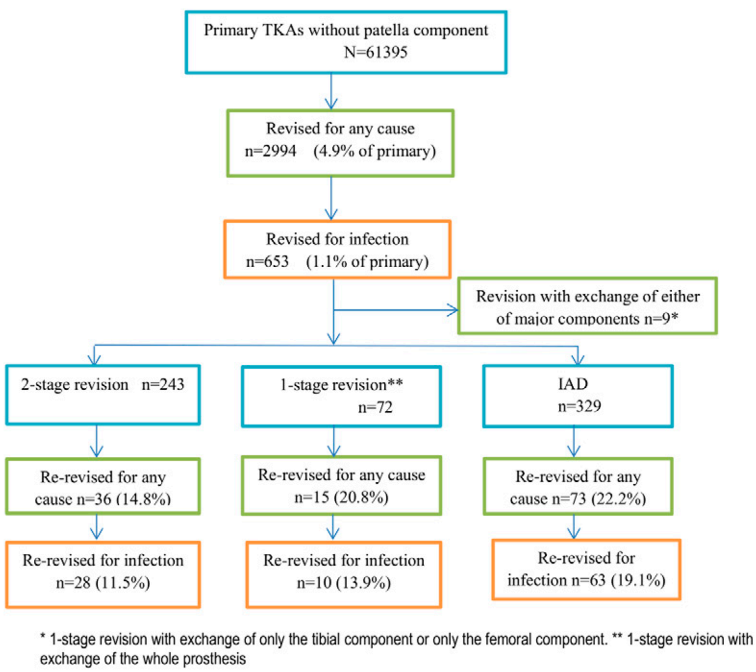

Fig. 1

Flowchart showing the cohort of TKAs without a patellar component in Norway in the period between 1994 and 2016 as well as the different subgroups of surgical procedures (number and percentage) for revisions that were performed because of infection. TKAs = total knee arthroplasties, and IAD = irrigation and debridement.

TABLE I Baseline Characteristics for Irrigation and Debridement, 1-Stage Revision, and 2-Stage Revision Procedures for Infected TKAs Between 1994 and 2016

Variables	Type of Revision Procedure			All Revision Cases (1994-2016)	
	Irrigation and Debridement (N = 329)	1-Stage Revision (N = 72)	2-Stage Revision (N = 243)	Due to PJI (N = 644)	Aseptic Revision (N = 2,269)
Mean age (SD) at revision *(yr)*	69 (10.5)	69 (9.5)	69 (9.7)	69 (10.1)	68 (10.7)
Women *(no. [%])*	138 (41.9%)	45 (62.5%)	138 (56.8%)	321 (49.8%)	1,534 (67.6%)
Cement use at revision* *(no. [%])*	275 (84%)	60 (83.3%)	179 (74%)	546 (84.8%)	1,917 (84.5%)
Mean time interval (SD) between primary and revision operations *(yr)*	1.1 (2.3)	2.7 (3.0)	2.5 (2.9)	1.8 (2.7)	3.3 (3.3)
Primary diagnosis *(no. [%])*					
Osteoarthritis	248 (75.4%)	55 (74.1%)	186 (75.6%)	489 (75.9%)	1,747 (77.0%)
Rheumatoid arthritis	20 (6.1%)	3 (4.2%)	16 (6.6%)	39 (6.1%)	119 (5.2%)
Posttraumatic arthritis	52 (15.8%)	11 (15.3%)	33 (13.6%)	96 (14.9%)	317 (14.0%)
Others	9 (2.7%)	3 (4.2%)	8 (3.7%)	20 (3.1%)	86 (3.8%)

*For the irrigation and debridement procedure, the cement usage values refers to the primary arthroplasties TKA = total knee arthroplasty, PJI = periprosthetic joint infection, and SD = standard deviation.

data more homogeneous and comparable, 9 knees with exchange of only the tibial or the femoral component via a 1-stage revision were excluded. Thus, 644 knees that underwent revision were included in the analysis (Fig. 1).

The NAR is a nationwide prospective register that has collected data since January 1994 for all knee arthroplasties

TABLE II Survival Index Revision for Infection by Procedure, Date, and Cause, with Any Cause and Infection as the End Points*

Revision Procedures	Second Revision *(no.)*		Kaplan-Meier Survival Free of Revision (95% CI) *(%)*				No. at Risk After 5 Yr
			For Any Cause		For Infection		
	For Any Cause	For Infection	1 Yr	5 Yr	1 Yr	5 Yr	
1994-2016							
Irrigation and debridement (n = 329)	73	63	81.6 (77.3-85.9)	75.9 (71.0-80.8)	82.9 (78.8-87.0)	79.0 (74.3-83.7)	130
1-stage (n = 72)	15	10	88.7 (82.1-96.1)	80.8 (71.4-90.2)	89.9 (82.8-97.0)	86.7 (78.7-94.7)	41
2-stage (n = 243)	36	28	91.6 (88.1-95.1)	83.8 (78.9-88.7)	93.3 (90.2-96.4)	87.3 (82.8-91.8)	99
Overall (n = 644)	124	101	86.2 (83.5-89.9)	79.4 (76.0-82.7)	87.6 (85.1-90.1)	82.9 (79.8-86.0)	270
1994-2004							
Irrigation and debridement (n = 20)	10	8	65.0 (44.2-86.0)	50.0 (28.0-72.0)	69.3 (48.7-89.9)	58.7 (35.3-82.1)	10
1-stage (n = 26)	4	3	92.3 (82.1-100.0)	88.5 (76.2-100.0)	92.3 (82.1-100.0)	88.5 (76.2-100.0)	23
2-stage (n = 49)	6	5	93.9 (87.2-100.0)	87.8 (78.7-96.9)	93.9 (87.2-100.0)	89.7 (81.1-98.3)	43
Overall (n = 95)	20	16	87.4 (80.7-94.1)	80.0 (72.0-88.0)	88.4 (81.9-94.9)	83.0 (75.4-90.6)	76
2005-2016							
Irrigation and debridement (n = 309)	63	55	82.7 (78.4-87.0)	77.9 (73.0-82.8)	83.8 (79.5-88.1)	80.6 (75.9-85.3)	89
1-stage (n = 46)	11	7	86.7 (76.7-96.7)	75.9 (62.8-89.0)	88.7 (79.3-89.1)	86.1 (75.7-96.5)	18
2-stage (n = 194)	30	23	90.9 (86.8-95.0)	82.5 (76.6-88.4)	93.1 (89.6-96.6)	86.4 (80.9-91.9)	87
Overall (n = 549)	104	85	86.0 (83.1-88.9)	79.3 (75.6-83.0)	87.5 (84.8-90.2)	83.0 (79.6-86.3)	194

*CI = confidence interval.

that have been performed in Norway. All primary and revision knee arthroplasties are reported individually by the orthopaedic surgeon, who fills in a 1-page form immediately after surgery[21]. The unique identification number of each Norway resident links information from any subsequent revisions to the primary operation.

The orthopaedic surgeon reports the reason for revision and any diagnosis of infection. Thus, diagnoses of infection were based on the surgeon's and the hospital's assessment of PJI and the clinical picture during revision surgery. Multiple reasons for revision may be reported; however, any reasons beside infection were treated as secondary reasons in this study. Based on what was reported by the orthopaedic surgeons and recorded in the NAR database, we determined whether the revised TKAs involved irrigation and debridement, a 1-stage procedure, or a 2-stage procedure. Accordingly, revision procedures were categorized as follows: (1) irrigation and debridement if only the liner was exchanged and/or a debridement was reported, (2) a 1-stage revision if there was exchange of both the tibial and femoral components or an exchange of the whole prosthesis and no insertion of a cement spacer, and (3) a 2-stage revision if there was removal of the whole prosthesis and insertion of a cement spacer, with later removal of the cement spacer and insertion of a whole prosthesis.

Definitions

Revision is defined as the removal, addition, and/or exchange of part of an implant or the whole implant. A "second revision" is defined as a subsequent revision. Since the NAR records revision surgery because of deep infection, in this study, PJI means only surgically treated PJI and excludes superficial infections and infections that were treated only with antibiotics.

Outcome Parameters

Survival rates, risk of revision, and mortality rates were assessed for the 3 surgical revision procedures (irrigation and debridement, 1-stage revision, and 2-stage revision). The success rates of 1-stage and 2-stage revisions also were compared based on those outcome parameters. The NAR identifies patients who had died or emigrated during follow-up from files provided by Statistics Norway (the Norwegian statistics bureau), but lacks data on the cause of death.

We stratified the patients by time from primary arthroplasty to index revision (<4 weeks, 4 to 12 weeks, and >12 weeks) to assess the effect of this time span on the risk of revision. Furthermore, we performed separate analyses for revisions that were performed in 1994 to 2004 and for those that were performed in 2005 to 2016 to investigate the effect of the year of operation on the outcomes of the revision of infected TKAs.

Statistics

Survival analyses were performed using the Kaplan-Meier method. Follow-up time was censored at the date of death or emigration. Patients who were not censored were followed until December 31, 2016. Multiple Cox regression analyses were performed to study the relative risk (RR) of revision following the 3 revision procedures, with adjustments for sex, age at revision, type of fixation, year of revision, time interval between primary and revision surgery, and diagnosis at primary surgery.

In all of the analyses, crude and adjusted results are presented with a 95% confidence interval (CI); p values < 0.05

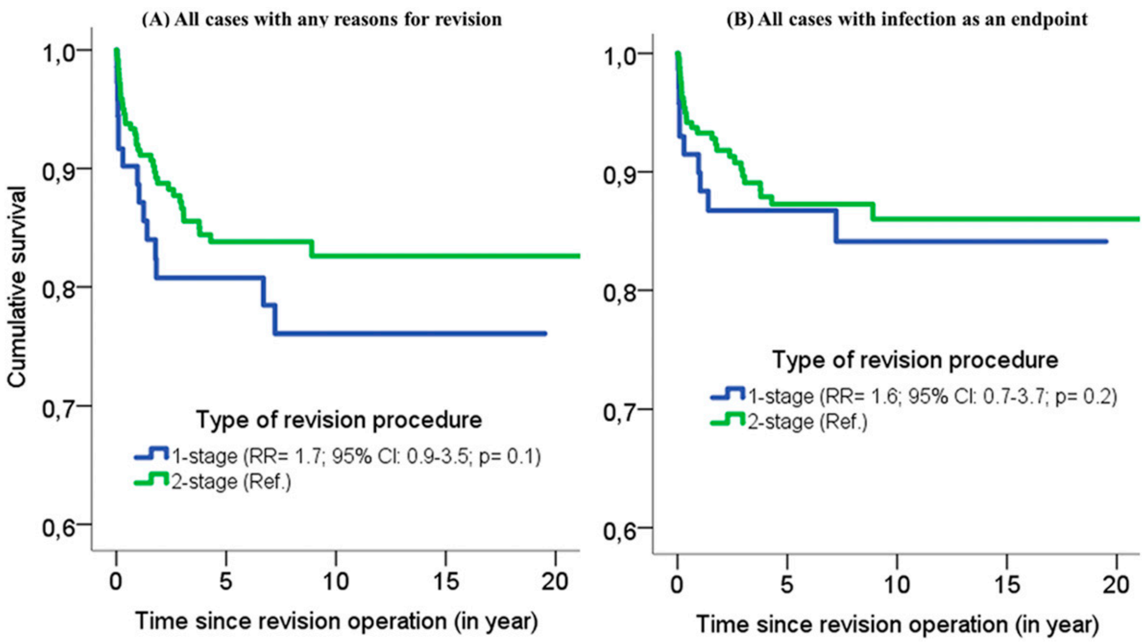

Fig. 2

Kaplan-Meier survival curves and multiple Cox regression analyses for relative risk (RR) of subsequent revision after revision of an infected knee arthroplasty for any reason (**Fig. 2-A**) and for infection (**Fig. 2-B**) as the end point. CI = confidence interval, and Ref = reference.

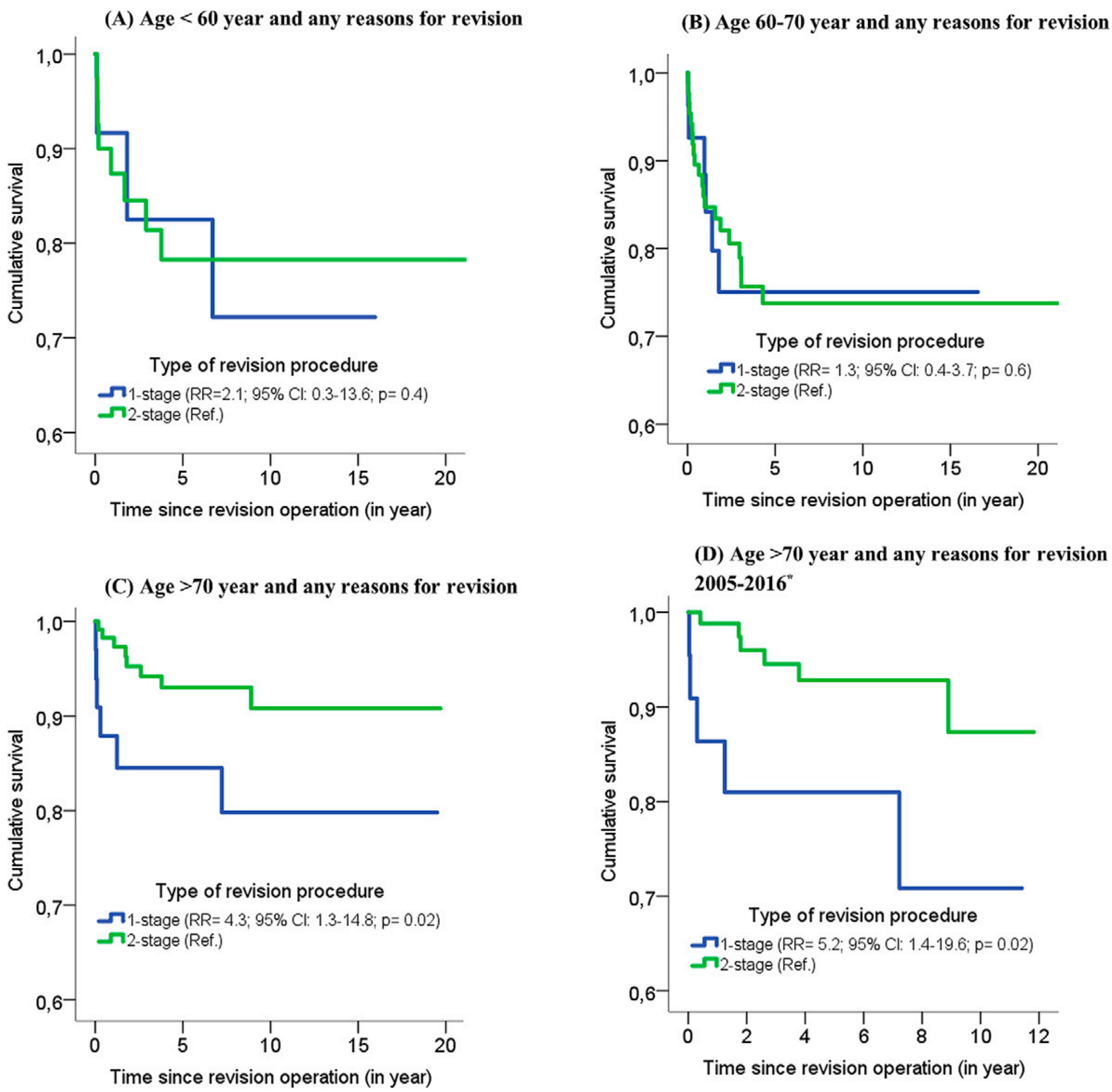

Fig. 3

Kaplan-Meier survival curves and multiple Cox regression analyses for relative risk (RR) of subsequent revision after revision of infected knee arthroplasty for any reason and age-stratified analyses (1994-2016) (**Figs. 3-A, 3-B, and 3-C**), as well as for patients who were >70 years old and for the period from 2005 to 2016 (**Fig. 3-C and 3-D**). *Multiple Cox regression analysis has been adjusted for the American Society of Anesthesiologists classification system. CI = confidence interval, and Ref = reference.

were considered significant. SPSS version 24 (IBM) was used to perform the statistical analyses.

Ethics Clearance

The NAR has a license from the Norwegian Data Inspectorate (reference number: 03/00058-20/CGN; date of issue: latest license, September 15, 2014).

Results

Descriptive Results

Of the 644 primary TKAs without patellar components that were revised because of PJI, 329, 72, and 243 revisions were performed with irrigation and debridement, 1-stage revision, and 2-stage revision, respectively (Fig. 1). The majority (80%) of cases had cemented fixation of the implant, 76% of the cases had osteoarthritis as the diagnosis for the primary surgery, 49.8% of the patients were women, the mean age at revision was 69 years, and the mean time interval between the primary and the revision surgery was 1.8 years (Table I).

Survival Rate (1994 to 2016)

Of the 644 TKAs, 124 (19.3%) underwent subsequent revision; 101 (81.5%) of those revisions were because of infection, and the mean follow-up after revision for infection was 5.1 years (range, 0.01 to 21.9 years). Of all of the cases that were revised with irrigation and debridement, 1-stage revision, and 2-stage revision procedures, 63, 10, and 28 cases, respectively, had a subsequent revision because of infection (Fig. 1). For the 63 cases with a subsequent revision after an irrigation and debridement

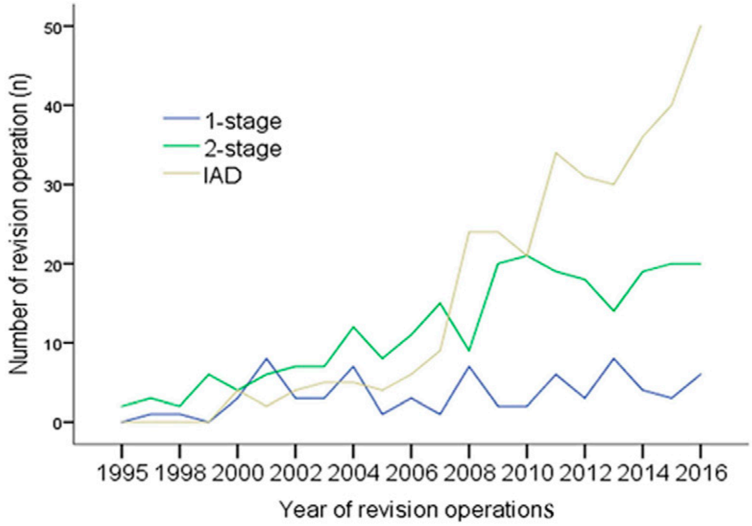

Fig. 4

Annual number of total knee arthroplasties that were revised for infection with an irrigation and debridement procedure (IAD), a 1-stage revision, or a 2-stage revision procedure in the period between 1995 and 2016.

procedure, 13, 11, and 39 cases were revised with irrigation and debridement, 1-stage revision, and 2-stage revision, respectively. The Kaplan-Meier survival percentages at 1 and 5 years following the 3 surgical procedures are given in Table II. The 5-year Kaplan-Meier survival rate with revision for infection as the end point was 79% after irrigation and debridement, 87% after 1-stage revision, and 87% after 2-stage revision.

No significant differences in risk of revision for any reason or risk of revision because of infection were found between 1-stage revision and 2-stage revision (Fig. 2). In an age-stratified analysis, however, the risk of revision for any cause was 4 times higher after a 1-stage revision than after a 2-stage revision for patients who were >70 years old (RR, 4.3; 95% CI, 1.3 to 14.8; p = 0.02) (Fig. 3), but the risk of revision because of infection was similar (data not shown). Compared with patients who were >70 years of age who underwent revision with the irrigation and debridement procedure, younger patients had a similar risk of revision for any reason (<60 years: RR, 1.0; 95% CI, 0.5 to 1.9; p = 1.0; 60 to 70 years: RR, 1.0; 95% CI, 0.6 to 1.8; p = 0.9) and a similar risk of revision because of infection (<60 years: RR, 0.9; 95% CI, 0.5 to 1.9; p = 0.9; 60-70 years: RR, 0.9; 95% CI, 0.5 to 1.6; p = 0.7).

Year of Revision Operations

A marked increase in the frequency of revisions because of infection was observed, particularly using irrigation and debridement procedures, from 2005 onward (Fig. 4). Therefore, we divided patients into 2 groups according to the time of revision (Table II). The 1-year and 5-year Kaplan-Meier survival percentages for revision because of infection from 1994 to 2004 and from 2005 to 2016 are presented in Table II. There was no significant difference between the time periods, although there seemed to be a trend toward a higher risk with a 1-stage revision than with a 2-stage revision in the last period (2005 to 2016). However, the observed difference was not significant (RR, 1.9; 95% CI, 0.7 to 4.7; p = 0.2). The survival rate for irrigation and debridement was lower from 1994 to 2004 than from 2005 to 2016 (Table II). The number of cases of irrigation and debridement was too low in the first period (1994 to 2004) to make any meaningful statistical comparison; thus, the results should be interpreted with caution.

Time Interval Between the Primary and the Revision Operation

In order to assess the effect on the outcome of the time interval between the primary and revision operations, we performed separate analyses for revisions that were performed before 4 weeks (24% of revisions), between 4 and 12 weeks (13% of revisions), and at >12 weeks (63% of revisions) after the

TABLE III Time Interval Between Primary TKA and Index Revision for Infection by Revision Procedure

Revision Procedures	Time Interval		
	<4 Wk *(no. [%])*	4-12 Wk *(no. [%])*	>12 Wk *(no. [%])*
Irrigation and debridement (n = 329)	147 (44.6%)	66 (20.1%)	116 (35.3%)
1-stage (n = 72)	0 (0.0%)	1 (1.4%)	71 (98.6%)
2-stage (n = 243)	8 (3.3%)	17 (6.8%)	218 (89.7%)
Total (n = 644)	155 (24.1%)	84 (13.0%)	405 (62.9%)

TABLE IV Mortality Rate After Revision by Procedure

	No. of Deaths	
Revision Procedures	Within 90 Days *(no. [%])*	Within 1 Yr *(no. [%])*
Irrigation and debridement (n = 329)	7 (2.1%)	12 (3.6%)
1-stage (n = 72)	0 (0%)	0 (0%)
2-stage (n = 243)	1 (0.4%)	4 (1.6%)
Total (n = 644)	8 (1.2%)	16 (2.5%)

primary operation (Table III). The mean time interval was shorter for the irrigation and debridement group than for the other 2 groups (Table I). In the multiple Cox regression analysis, we found no significant effect of the time interval between the primary and revision operation on the risk of revision following an irrigation and debridement procedure, either for any reason (<4 weeks: RR, 1.1; 95% CI, 0.7 to 2.0; p = 0.6; 4-12 weeks: RR, 1.5; 95% CI, 0.7 to 2.8; p = 0.2) or because of infection (<4 weeks: RR, 1.2; 95% CI, 0.7 to 2.1; p = 0.6; 4-12 weeks: RR, 1.5; 95% CI, 0.9 to 3.0; p = 0.2).

Mortality Rate

The 90-day and 1-year mortality rates after revision because of infection were 1.2% and 2.5%, respectively (2.1% and 3.6% after irrigation and debridement, 0% and 0% after 1-stage revision, and 0.4% and 1.6% after 2-stage revision, respectively) (Table IV). There were no significant differences in the risk of death after the 1-stage versus the 2-stage revision procedure (data not shown).

Discussion

During the follow-up period, 19%, 14%, and 12% of patients who had been treated with irrigation and debridement, 1-stage revision, and 2-stage revision, respectively, underwent a subsequent revision because of PJI. The 5-year Kaplan-Meier survival rate with revision for infection as the end point was 79% after irrigation and debridement, 87% after 1-stage revision, and 87% after 2-stage revision. Overall, there were no significant differences in survival percentage and risk of revision between 1-stage revision and 2-stage revision, either for any reason or for infection as the end point. However, in an age-stratified analysis, the risk of revision for any reason was 4 times higher after 1-stage revision than after 2-stage revision for patients who were >70 years old, while the risk of revision because of infection was similar. Age had no significant influence on the outcome after irrigation and debridement. The 90-day and 1-year mortality rates after revision for PJI were 1.2% and 2.5%, respectively. Relatively higher mortality percentages (3.6%) within 1 year of follow-up were observed in patients who had undergone irrigation and debridement.

Explanations, Mechanisms, and Comparison with Other Relevant Studies

PJI is a relatively rare but challenging[22] complication that is associated with increased length of hospital stay, more readmissions, subsequent revisions, increased morbidity, and even mortality[23-27]. Irrigation and debridement, 1-stage revision, and 2-stage revision are the 3 most frequently used surgical treatment options for PJI[28,29]. However, there is no consensus on the best surgical treatment for PJI after primary knee arthroplasty, and prospective randomized controlled trials to compare different treatment modalities are lacking and may not be feasible[30].

Some studies have claimed that the 2-stage revision procedure is the standard for treating PJIs[13-16], whereas others have claimed that 2-stage revisions are complex and require advanced reconstructive strategies, multiple surgeries, and longer operative time, leading to more morbidity and less favorable functional results; therefore, these studies advocate exchanging the implant in a single operation[17,31,32]. Most of the reviewed studies concluded that the outcomes of revision because of PJI in patients who were treated with 2-stage revision could be expected to be similar or superior to the outcomes of PJI revisions in patients who were treated with 1-stage revision, citing the survival rate or rate of revision because of infection as an outcome measure; however, they concluded that outcomes would be similar or inferior to 1-stage revision in terms of functioning[33,34]. Similarly, irrigation and debridement has been reported to be an attractive treatment option for PJI because of its low morbidity[35]. However, a high failure rate (15% to 73%)[36] and negative effects on the results of subsequent implant revision procedures have been reported[37].

Survival Rate

We found no significant difference in survival rate or risk of subsequent revision between patients with 1-stage and 2-stage revisions. This concurs with the findings of some previous studies[3,13,28,38,39]. Castellani et al. reviewed studies of infected TKAs and found no significant difference in the rate of infection eradication between 1-stage and 2-stage revisions (94% and 84% success rate, respectively)[38]. Similarly, a systematic review by Nagra et al. reported no significant differences in risk of reinfection between the 2 treatment options[28]. However, some other reviews have reported a higher success rate with 2-stage revisions in the eradication of infection compared with that of 1-stage revisions[30,40,41].

In their meta-analysis, Romanò et al. reported an eradication rate of 90% for 2-stage revisions and 82% for 1-stage revisions at an average follow-up of 45 months[30]. One possible explanation for this inconsistent finding could be that medical and surgical treatments are chosen individually by the treating surgeon and on the basis of different clinical settings, such as a requirement for identified and sensitive microorganisms if 1-stage revision is selected. Castellani et al. reported that the choice of 1-stage revision was most influenced by surgeon preferences and was 3 times more likely for hip revision than for knee revision (odds ratio [OR], 3.39; 95% CI, 1.85 to 6.23)[38]. In Norway, treatment decisions are based on the experience and strategies of the individual surgeon and the hospital. The 2-stage revision procedure is usually used for more severe infections (e.g., long-standing infections, fistulas, and difficult-to-treat bacteria) or after failed irrigation and debridement procedures, whereas 1-stage revisions tend to be used in less severe cases (e.g., more recent infections and familiar and easy-to-treat bacteria).

In the present study, we found a higher success rate (79% at 5 years) with irrigation and debridement than the 36% to 77% success rate that had been reported in previous studies[19,20,35,42-47]. The wide variation in success or failure rates with irrigation and debridement that has been reported by different studies could be attributed to variations in patient characteristics, the duration of the infection, the infecting microorganisms, the proportion of methicillin-resistant *Staphylococcus aureus* (MRSA) infections, the choice and execution of the procedure, single or multiple debridement procedures, the antibiotic choice, the duration of antibiotic use, outcome variables, etc[36,48]. A register study on revision knee arthroplasties from Sweden, a country with a similar treatment policy and organization of health care to Norway, reported a 75% success rate of irrigation and debridement procedures[20], which is comparable with our study. Two studies (1 single-center and 1 register study) on revision hip arthroplasty reported success rates of 71% (27 of 38 hips)[49] and 76%[50] for irrigation and debridement procedures, respectively.

It is generally agreed that irrigation and debridement is indicated for cases with a short history of infection, whereas implant exchange is preferred for chronic cases. Despite the higher failure rate, treatment of PJI with irrigation and debridement remains popular because of the perceived advantages, including a technically less demanding procedure that can be performed in a short operative time with low perioperative morbidity and relatively good functional results[37].

Risk Factors

There are controversies regarding the factors that affect the outcome of revision following a knee PJI. The importance of the time interval from the onset of symptoms to the revision or between the primary and revision operation in regard to choosing the appropriate treatment is stressed in the literature. For example, the irrigation and debridement procedure has been recommended for patients with a well-fixed major prosthesis component and early PJI within 30 days of the primary operation or for acute PJIs with a symptom duration of <3 weeks[51]. According to Nakano et al., factors such as the time of onset of symptoms after primary TKA, the type of hospital where the primary operation was performed, and the organism's resistance to methicillin are important factors that influence clinical outcomes after an infected TKA[52]. One factor contributing to the high success rate of irrigation and debridement in the present study might be the low rate of infections due to MRSA in Norway. Lutro et al., in their study on hip arthroplasty, found no cases of infection due to MRSA in Norway[53].

In our study, the type of primary diagnosis, the type of fixation, the year of the revision operation, and the time interval between the primary and revision operations did not appear to affect the infection eradication rate following any of the surgical treatment procedures. A review study by Jämsen et al. reported no significant effect of the type of primary diagnosis and mean age on the rate of postrevision infection[40]. Similarly, other previous studies have reported no significant effect of the time interval between the primary and revision operations on the success or failure rate with a PJI that was treated with irrigation and debridement[20,50,54]. The present study lacks information on the date of symptom onset and classification (i.e., early, subacute, late chronic, or late hematogenous); however, studies from Spain[55] and Sweden[20] reported no significant effect of the duration of infection symptoms on the success rate of the irrigation and debridement procedure.

Mortality Rate

In patients who underwent revision surgery due to infection, we found that 1.2% died within 90 days and 2.5% died within 1 year. However, we lack data on the cause of death and, thus, it is not possible to determine whether the deaths were related to the PJI or the surgical procedure. Boddapati et al. reported that revision of an infected TKA had a significantly higher mortality rate compared with aseptic revision of a TKA (adjusted OR, 3.25)[27]. Cobo et al., in their study on outcomes of PJI treatment with irrigation and debridement, reported a mortality rate of 3.6% at 2.5 years of follow-up[43], which is similar to our finding (i.e., 3.6% rate of death within 1 year after irrigation and debridement) but with longer follow-up. However, a study from the Danish Knee Arthroplasty Register reported higher 90-day mortality rates (3% after irrigation and debridement and 5% after 2-stage revision)[47] than our study. Lie et al. found that the 1-year mortality rate after primary hip and knee arthroplasty was lower than in the general population[56].

Strengths and Limitations

The NAR is an established large prospective observational arthroplasty register with national coverage and a high inclusion of primary cases (>95%)[57,58], which is reassuring for the generalizability of the study findings. However, our study has some limitations. First, the NAR does not collect information on microbiology results, body mass index, the American Society of Anesthesiologists (ASA) classification system (before 2005), steroid use, etc. The diagnosis of infection is based on the surgeon's opinion just after surgery, before the results of the tissue cultures have been received. Therefore, the diagnosis is not validated for all cases. The NAR started to collect data based on the ASA classification system in 2005, and a subanalysis that was adjusted based on the ASA classification system did not alter the findings (data not shown). Second, a validation study by Arthursson et al. revealed that 10.5% of revision arthroplasties performed because of infection were not reported to the NAR[57]. However, the authors reported that missing data on revisions had only a minor influence on the results of the survival analysis. Thus, there is no reason to believe that the underreporting of infection cases would cause systematic bias and consequently alter our findings. Third, the possible preference of surgeons for the 2-stage procedure when infections were more difficult to treat could bias the comparison in favor of 1-stage revision. Surgeons also may tend to choose the 1-stage approach for sicker patients who they think will not tolerate a 2-stage procedure. Fourth, a 90% survival rate after revision does not mean that 90% of the infections were eradicated. Patients may still be infected and undergoing suppressive medical treatment with antibiotics. Thus, in order to present the full picture of treatment outcomes, patient-reported functioning, pain, and satisfaction also need to be taken into consideration.

Overview

In our study, irrigation and debridement had good results compared with previously published studies. Although 1-stage revisions showed a fourfold increase in risk of subsequent revision for any reason compared with 2-stage revisions in patients who were >70 years old, the overall outcomes after 1-stage and 2-stage revisions were similar. These results have implications for patient counseling and alternative treatment strategies for an infected joint following arthroplasty, including revision TKA. Because of the study limitations, we cannot recommend one procedure over the other. The indications for the various strategies are different, and our results are prone to bias by indication. Thus, prospective randomized controlled trials comparing treatment modalities are required to validate our findings.

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