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Early revision rate in robotic-assisted total knee arthroplasty compared to conventional total knee arthroplasty based on the Finnish Arthroplasty Register in prospective cohort study

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Summary:

Total knee arthroplasty (TKA) is an effective treatment for relieving pain in advanced knee osteoarthritis. Robotic-assisted total knee arthroplasty (rTKA) has been introduced to improve surgical precision and outcomes, but evidence on its effect on implant survival is limited. The aim of this study was to compare early implant survival between rTKA and conventional total knee arthroplasty (cTKA). The survival endpoint was the first revision. Revisions due to periprosthetic joint infection (PJI), or due to reasons other than PJI were considered as secondary endpoints.

Using data from the Finnish Arthroplasty Register (FAR) and the Care Register for Health Care (HILMO), all 1,347 MAKO rTKAs performed in Finland up to May 2023 were identified and compared with 40,274 cTKAs using the same Triathlon implant system between 2014 and 2023.

At one year, Kaplan–Meier revision-free survival was 99.1% for rTKA and 98.5% for cTKA. There were 10 revisions in the rTKA group and 603 in the cTKA group, with PJI being the most common cause of revision in both cohorts. Cox regression analyses suggested a borderline significant reduction in revision risk with rTKA compared to cTKA, particularly within the first three months after the index surgery. A similar borderline reduction was observed for revisions due to PJI, while no difference was found for revisions due to other causes. Based on the results, early implant survival after rTKA was at least as good as after cTKA.

Early revision rate in robotic-assisted total knee arthroplasty compared to conventional total knee arthroplasty based on the Finnish Arthroplasty Register in prospective cohort study

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Key words

Total knee arthroplasty (TKA), robotic-assisted total knee arthroplasty (rTKA), conventional total knee arthroplasty (cTKA), revision arthroplasty, prosthetic complication, periprosthetic infection

Abstract

Background and purpose

Robotic-assisted total knee arthroplasty (rTKA) has been proposed to improve component positioning and patient outcomes but evidence on its effect on implant survival is limited. Our objective was to compare implant survival between rTKA and conventional total knee arthroplasty (cTKA), with a specific focus on revisions due to prosthetic joint infection (PJI).

Methods

We included all 1,347 fixed bearing rTKA operations performed in Finland until May 2023, all implanted with Triathlon TKA using MAKO robotic-arm assist. Control group was all 40,274 cTKAs with identical implants performed from May 2014 to May 2023. Survival endpoint was first revision. Overall survival was assessed using Kaplan-Meier (KM) analysis. Cox proportional hazards models were used to estimate hazard ratios (HR) with 95% confidence intervals (CIs) for revision within 12 months of surgery.

Results

rTKAs demonstrated better short-term survival with KM estimates 99.1% (95% CI: 98.5-99.7) for rTKA and 98.5% (95% CI: 98.3-98.6) for cTKA within the first year after the index surgery. Compared to cTKAs, rTKAs demonstrated borderline significant trend towards nearly halving the risk of revision (unadjusted HR=0.57; 95% CI: 0.31-1.07; adjusted HR=0.60; 95% CI: 0.32-1.13) within the first 12 months. Similarly borderline significant reduction in PJI risk was observed in rTKA group. In both cohorts, PJI was the most common reason for revision.

Conclusion:

We found that the first-year revision risk was lower in the rTKA group compared to the cTKA group. Further research is needed to see if robotics can really decrease revision surgeries and especially PJI revisions.

Introduction

Conventional total knee arthroplasty (cTKA) is an effective treatment for relieving pain in advanced knee osteoarthritis (OA).(1,2) However, as many as 20% of the patients are somewhat dissatisfied with their outcome.(3) Currently robotic-assisted TKA (rTKA) is increasingly utilized to improve the outcome of knee surgery. rTKA technology may improve cost efficiency, surgical precision and patient outcomes.(4,5) Zhang et al. found significantly less deviation between planned and actual component position in rTKA compared to cTKA suggesting improved surgical precision. They also found that rTKAs resulted in better Knee Society Score and Western Ontario and McMaster Universities Osteoarthritis Index scores measuring functional outcomes. The review by Pipino et al. showed that rTKA not only improved surgical accuracy but also reduced healthcare costs and readmission rates. So far, however, there is limited data on short-term revision rates compared to cTKA. With the increased usage of rTKA, understanding its impact on revision and complication rates is crucial.

In Finland four hospitals (Kuopio University Hospital, Oulu University Hospital, Satakunta Central Hospital and Mikkeli Central Hospital) use the MAKO robotic arm assisted Triathlon TKA (Stryker, Kalamazoo, MI, USA) in everyday practice. The Finnish Arthroplasty Register (FAR) and the Care Register for Health Care (HILMO) collect data on TKA outcomes in Finland, including also if the procedure was assisted with a robot arm or not. In this study our aim was to assess early revision rates of rTKA and cTKA based on FAR and HILMO data. Our hypothesis was that the early revision rate of rTKA and cTKA is essentially the same.

Methods

FAR was established in 1980 and compiles arthroplasty data nationally. HILMO is a national register for all Finnish healthcare and social services that gathers information about all healthcare services including diagnoses and surgical operations. Reporting TKA operations to FAR and HILMO is mandatory. Both registers are maintained by the Finnish Institute of Health and Welfare. Linking primary and revision operations and death of the patient is performed using a unique social security number. Since May 2014, implants have been identified by the electronic reading of reference codes perioperatively. Operative data are sent electronically to FAR and HILMO. In May 2014, the data content of the FAR was examined and revised. The updated data now include detailed information on items such as patient body mass index (BMI) and American Society of Anesthesiologists (ASA) class, surgical approach, and possible use of a navigate system or robotic-assisted surgery. All arthroplasty units deliver data; thus, the coverage of hospitals is 100%. According to the FAR, the completeness of data is >98% for primary TKA and >92% for revision TKA(6). By linking HILMO data with FAR it is possible to include comorbidity data of the patients and count the Charlson index, and also to increase completeness in identifying rTKAs.

MAKO robotic-arm assisted TKA system utilizing Triathlon device or MAKO unicompartmental knee arthroplasty (UKA) utilizing Restoris MCK device are the only robotic-arm systems that are currently used in Finland. Primary MAKO rTKAs started in April 2021 and are currently used in four Finnish public hospitals: Satakunta Central Hospital, Mikkeli Central Hospital, Oulu University Hospital and Kuopio University Hospital. From the FAR we extracted all primary TKAs with a MAKO-compatible device from the new FAR era (Figure 1). Among these, we identified all robotic-arm assisted procedures, performed between April 2021 and May 2023, based on the procedural codes in the FAR and complemented the cohort with those reported to the HILMO register. Next, we excluded UKAs as well as all TKAs except tibiofemoral prostheses with mobile bearing to arrive at our final rTKA cohort (n=1,347). From the remaining Triathlon devices, after similar exclusions, we

formed our cTKA cohort (n=40,274) to be used as a reference group in the comparisons of implant survival with the rTKAs.

Our aim was to compare short-term implant survival between the two groups. The survival endpoint was the first revision operation in which one or more prosthesis components were removed or exchanged for any reason after the index surgery. Revisions due to periprosthetic joint infection (PJI), or due to reasons other than PJI were considered as secondary endpoints. The median follow up time in the rTKA cohort was 11.5 months (range: 0.1–24.8 months). The patients were censored at data cutoff on May 7, 2023, or at the time of death. There were 7 (0.5%) deaths in the rTKA group and 222 (0.6%) in the cTKA group within the first year, so mortality was similar in both groups. We treated bilateral operations as separate independent observations as bilateral operation has previously been shown to have minimal effect on implant survival.(7)

Overall implant survivorships with 95% confidence intervals (CI) were estimated using Kaplan-Meier analysis. The survival curves for rTKAs and cTKAs were compared using the log-rank test. Univariable and multivariable Cox proportional hazards models were used to estimate hazard ratios (HR) with 95% CIs for revision operation within the first year after the index surgery. Potential risk factors based on previous literature were used to adjust the multivariable analysis(8). Such risk factors were age at primary operation (<60, 60-69, 70-79, ≥80 years), Charlson comorbidity index (0-37 points), BMI (underweight <18.5, normal weight 18.5-24.9, overweight 25-29.9, obese ≥30, severe obesity ≥40), primary diagnosis (primary OA or other), prosthesis constraint (CR (cruciate retaining)/PS (posterior stabilized)) and the use of patellar component. To reveal the time window with greatest differences in revision risk between rTKA and cTKA cohorts, the HR estimates were also evaluated in three-month intervals. The proportional hazards (PH) assumption for Cox analyses were assessed from Kaplan-Meier curves graphically and by test on scaled Schoenfeld residuals.(9,10) Competing risk analysis was not performed because mortality of the two groups was essentially the same. Comparisons between the characteristics of rTKA and cTKA cohorts were

performed using the Mann-Whitney *U* test for continuous variables and the chi-squared test for categorical variables. As a sensitivity analysis of our findings, we performed the comparisons between rTKA and cTKA cohorts separately also for patients with primary OA as their main indication for surgery. Statistical analyses were carried out using R statistical computing environment version 4.3.1 (R Core Team, 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/). The level of significance was set at $p<0.05$.

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Ethics, data sharing plan, funding, and potential conflicts of interest

Ethical approval: Dnro THL/2267/14.02.00/2022. For data-sharing purposes, extracted data is provided in the supplementary files.

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Results

Median age of the patients was 68 years in the rTKA group and 69 years in the cTKA group, most were women in both groups (63% in rTKA and 62% in cTKA cohorts, respectively) and belonged to ASA class II (55% in rTKA vs 54% in cTKA cohorts). Median Charlson was 3 points in rTKA and 4 points in cTKA group, whereas median BMI was 30.4 kg/m^2 and 29.7 kg/m^2, respectively. Primary

OA was the leading indication (98% in rTKA and 94% in cTKA) and the use of patellar resurfacing was uncommon (6% with rTKA and 13% with cTKA) in both groups. (Table 1)

During the first 12 months, there were 10 revisions in the rTKA group, and 603 in the cTKA group. The most common reason for revision was PJI in both groups (Table 2).

The overall Kaplan-Meier probabilities for revision-free implant survival differed between rTKA and cTKA cohorts (p=0.04) (Figure 2A). At 12 months after the index surgery, the estimated survival was 99.1% (95% CI 98.5–99.7) for the rTKA cohort and 98.5% (95% CI 98.34–98.6) for the cTKA cohort. At the end of the rTKA follow-up (25 months), the estimated survival was 97.8% (95% CI 95.1–100.0) for the rTKA cohort and 97.4% (95% CI 97.2-97.5) for the cTKA cohort.

Similar to overall revision, the rTKA cohort had better survival in terms of revision for PJI as endpoint compared to the cTKA cohort (p=0.05) (Figure 2B). The estimated survival at 12 months after the index surgery was 99.7 % (95% CI 99.4-100.0) for the rTKA cohort and 99.2 % (95% CI 99.1-99.3) for the cTKA cohort. In contrast, no differences in survival were observed between rTKA and cTKA cohorts for revisions due to other causes than PJI (Figure 2C).

In unadjusted Cox regression analysis, rTKA demonstrated borderline significant reduction in risk of revision within the first 12 months after the index surgery compared to cTKA (HR=0.57, 95% CI 0.31-1.07, p=0.08) (Table 3). Despite wider CIs, the effect remained similar in adjusted analysis (HR=0.60, 95% CI 0.32-1.13, p=0.11). Splitting the follow-up time in shorter time intervals revealed that the reduction in risk was most pronounced during the first three postoperative months (unadjusted HR=0.44, 95% CI 0.18-1.07, p=0.07; adjusted HR=0.45, 95% CI 0.19-1.10, p=0.08) whereas no noticeable differences were observed during later time intervals.

For revision due to PJI within the first 12 postoperative months, rTKA demonstrated borderline significant reduction in revision risk compared to cTKA in both unadjusted (HR=0.40, 95% CI 0.15-1.08, p=0.07) and adjusted (HR=0.42, 95% CI 0.16-1.12, p=0.08) Cox models. In the rTKA cohort,

all revisions due to PJI took place within the first six postoperative months. For revisions due to reasons other than PJI, no differences in revision risk were observed between rTKA and cTKA in either unadjusted (HR=0.80, 95% CI 0.36-1.80, p=0.59) or adjusted (HR=0.86, 95% CI 0.38-1.93, p=0.71) analysis.

All aforementioned findings remained similar in our sensitivity analysis consisting only of patients with primary OA as their main indication for surgery (Supplementary Material).

Discussion

This is the first study assessing revision rates of rTKA based on FAR. We included all rTKAs performed in Finland up to May 2023 and we found that early survival of rTKA was at least as good as that of cTKA. The Cox regression analyses suggested a borderline significant reduction in revision risk with rTKA compared to cTKA, particularly within the first three months after the index surgery.

Similar results have been reported from large arthroplasty registers(11) (12) but also contradictory data exist(13) (14). Ofa et al. analyzed 755,350 TKAs of which 5,228 were operated with robotic assistance with a minimum follow-up of one year. They found higher revision rate for the cTKA group compared to that of the rTKA (odds ratio [OR] 1.21). (11) 17,249 rTKAs and 541,122 cTKAs were assessed in the study by Aggarwal et al. and the authors found a reduced risk for PJI (OR 0.027), periprosthetic dislocation (OR 0.117), periprosthetic fracture (OR 0.28) and periprosthetic mechanical complications (OR 0.315) in rTKA in comparison to cTKA.(12) In a systematic review by Mancino et al. 614 rTKAs and 585 cTKAs were pooled and the authors found no difference in complication rates (2.4% and 1.4% respectively) nor in overall implant survivorship (98.3% and 97.3% respectively)(13). In a national cohort of 847,496 patients including 24,460 rTKAs there was no difference compared to cTKA regarding PJI, prosthesis breakage, dislocation, loosening and periprosthetic fracture nor overall revision risk.(14)

Previously in two smaller patient cohorts comparing cTKA and MAKO rTKA there were no differences concerning complications (15,16) Kayani et al. assessed 40 consecutive rTKA and 40 cTKA and the rTKA group had less postoperative pain and improved early mobilization, but there were no differences in complications during the 30-day follow-up time.(15) In a study by Mitchell et al. 139 consecutive cTKAs and 148 rTKAs were operated by a single surgeon with a minimum one year follow-up. Reduced postoperative pain and length of hospitalization, reduced need for physical therapy and lower rate of readmissions were associated with rTKA, but no difference was found in complication rates between the groups. In the rTKA group there were no revision operations, whereas in cTKA group revision occurrence was 0.63% including two deep infections.(16) Clement et al. found no difference in revision rates in a randomized controlled trial comparing manual TKAs and MAKO rTKAs. Totally 46 rTKAs and 41 cTKAs were reviewed for 6 months(17). To our knowledge only one meta-analysis has assessed specifically MAKO rTKA and cTKA outcome (Vermue et. al). Duration of the operation did not differ between the two groups, whereas surgical precision, ligament balance and alignment were better in the rTKA group. Most likely these attributes improved clinical outcomes during the first year. In the five studies included in the meta-analysis there were no differences in complications between rTKA and cTKA groups in short term.(18)

In the Australian Orthopedic Association National Joint Replacement Registry annual report 2024, there were no differences in revision rates when comparing cTKAs and rTKAs(19). At 6 years, the Kaplan-Meier survival probability for cTKAs was 96.9% (95% CI 96.8-97) and that for rTKAs 97.6% (97.3-97.9). The adjusted hazard ratio between the groups was 1.04 (0.96-1.13) p=0.3. However, the use of MAKO rTKA with Triathlon device was associated with lower revision rates than Triathlon cTKA (HR = 0.86, 95% CI: 0.75–0.99; p = 0.03). This difference increased when Triathlon TKAs with patella resurfacing was analyzed (HR = 0.74, 95% CI: 0.62–0.89; p = 0.001). Triathlon rTKA without patella resurfacing had similar revision rates compared to Triathlon cTKA (HR = 1.18, 95% CI: 0.96–1.46; p = 0.124). In our study we did not separately assess outcomes if patellar button was

used or not, but it was accounted for in the adjusted analysis. In our study the majority of TKAs were performed without patellar resurfacing (rTKA 94.2%, cTKA 87.2%).

So overall there have been only a few studies comparing rTKA to cTKA using one specific robotic system only and even fewer studies with the MAKO system. It is important to assess each rTKA system separately as there may be substantial differences between the systems(18). Many studies on MAKO rTKAs focus on functional outcomes and surgical accuracy, and not on early- to mid-term revision rates(20). The strength of our study was that we were able to assess a single robotic assisted system. Further, our study was based on large national arthroplasty register data which includes all robotic-assisted TKAs in Finland up to end of study period. This enables the assessment of how the modern method of knee arthroplasty has affected the short-term complication rates and how well the new technology has fared in Finland. In absence of large randomized controlled trials, unselected registers are the best source of data concerning surgical complications of rTKA.

Our data represents the first national results of a new technology in Finland, and therefore certainly includes surgeons with a learning curve. Also, during the learning phase easier knees with less malalignment or contracture might have been selected, although this may not always be the case. Further, during learning curve rTKA operation time may also be longer compared to cTKA(21)On the other hand, only specialists are allowed to perform MAKO rTKA after proper education, and only public large volume units perform rTKAs in Finland so far. While surgeon seniority and hospital size were not directly risk factors for PJI in a previous register study(8) the pronounced effect in this case could present as a confounding factor to revision risk.

Compared to HILMO, 98% of primary TKAs and 92-95% of revision TKAs were reported to FAR in 2021 and 2022, so overall completeness of FAR has increased lately(6). A limitation of our study is that we still miss some revision TKAs, especially those performed on call like revisions for PJIs. Especially, completeness of the revision TKA data of the two central hospitals involved in rTKA

surgery (Satakunta Central Hospital, Mikkeli Central Hospital) has been lower than average. Despite that we think that it is fair to say that the early revision rate of rTKA is at least not higher than that of cTKA. The overall number of rTKA revisions at this point was very small, only 10 revisions. Also, the follow-up time of 12 months was not reached in all of the rTKAs and cTKAs and as rTKA group is not vast this could affect the results of full 12-month revision rates. In theory rTKA method might aid in reducing septic complications due to less hand contact with the wound intraoperatively, and there may also be less surgical soft tissue trauma, less releases and bone exposure[22]. Further, opening of the intramedullary canal is not needed in rTKA. However, these effects could be negated by the extra personnel needed to operate the robot in operating room, slightly longer operation time on average, and possible extra skin wounds if intraoperative pins are inserted outside the parapatellar wound. Further, residual confounding may in part explain the decreased PJI risk of the rTKA group. A limitation of our study is that we did not have any data on radiological outcomes or patient reported outcome measures (PROMs). A longer follow-up time and larger cohorts are needed to assess any superiority of either technique.

Author contributions

KA and ES wrote the manuscript draft, MV analyzed statistics, KM designed the study and all authors contributed to the final the manuscript.

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Tables

Table 1. Demographics and clinical characteristics for robot-assisted total knee arthroplasty (rTKA) and non-robot-assisted total knee arthroplasty (cTKA) cohorts.

Variable	rTKA (n=1,347)	cTKA (n=40,274)	p
Age, median (IQR)	68 (13)	69 (13)	<0.001
Sex, n (%)			
Male	505 (37.5)	15,246 (37.9)	0.81
Female	842 (62.5)	25,028 (62.1)	
ASA, n (%)			0.65
I	83 (6.2)	2,727 (6.8)	
II	736 (54.6)	21,511 (53.9)	
III	519 (38.5)	15,353 (38.4)	
IV	9 (0.7)	351 (0.9)	
Charlson, median (IQR)	3 (3)	4 (3)	<0.001
BMI, median (IQR)	30.4 (7.3)	29.7 (6.7)	<0.001
Bilateral procedure, n (%)	57 (4.2)	1,906 (4.7)	0.43
Diagnosis, n (%)			<0.001
Primary osteoarthrosis	1,322 (98.1)	38,000 (94.4)	
Other or missing	25 (1.9)	2,274 (5.6)	
Operation TKA, n (%)			<0.001
without patellar resurfacing	1,269 (94.2)	35,131 (87.2)	
with patellar resurfacing	78 (5.8)	5,143 (12.8)	
Triathlon device, n (%)			<0.001
Cruciate retaining (CR)	1,302 (98.7)	38,421 (95.7)	
Posterior stabilized (PS)	17 (1.3)	1,741 (4.3)	

ASA = American Society of Anesthesiologists, BMI = body mass index, IQR = Interquartile range, TKA = total knee arthroplasty

Table 2. Reasons for revision within the first 12 months from the index surgery.

Reasons for revision, n (%)	rTKA (n=1,347)	cTKA (n=40,274)
Tibiofemoral instability	1 (0.07)	33 (0.08)
Patellofemoral instability	0 (0.00)	22 (0.05)
Malposition of component	1 (0.07)	24 (0.06)
Infection	4 (0.30)	321 (0.80)
Periprosthetic fracture (any)	1 (0.07)	26 (0.06)
Stiffness	0 (0.00)	14 (0.03)
Aseptic loosening	0 (0.00)	18 (0.04)
Pain	1 (0.07)	30 (0.07)
Other / reason missing	2 (0.15)	115 (0.29)
Combined	10 (0.74)	603 (1.50)

Table 3. Unadjusted and fully adjusted hazard ratio (HR) estimates for revision due to any reason as endpoint. The HRs were estimated overall for the first 12 months from the index surgery overall as well as within three-month time intervals.

Time interval (months)	Unadjusted			Adjusted		
	HR	(95% CI)	p	HR	(95% CI)	p
0-12	0.57	(0.31-1.07)	0.08	0.60	(0.32-1.13)	0.11
0-3	0.44	(0.18-1.07)	0.07	0.45	(0.19-1.10)	0.08
3-6	1.95	(0.37-10.26)	0.43	1.98	(0.38-10.39)	0.42
6-9	2.52	(0.48-13.21)	0.28	2.50	(0.47-13.12)	0.28
9-12	1.15	(0.09-9.99)	0.90	1.22	(0.14-10.58)	0.86

Figures

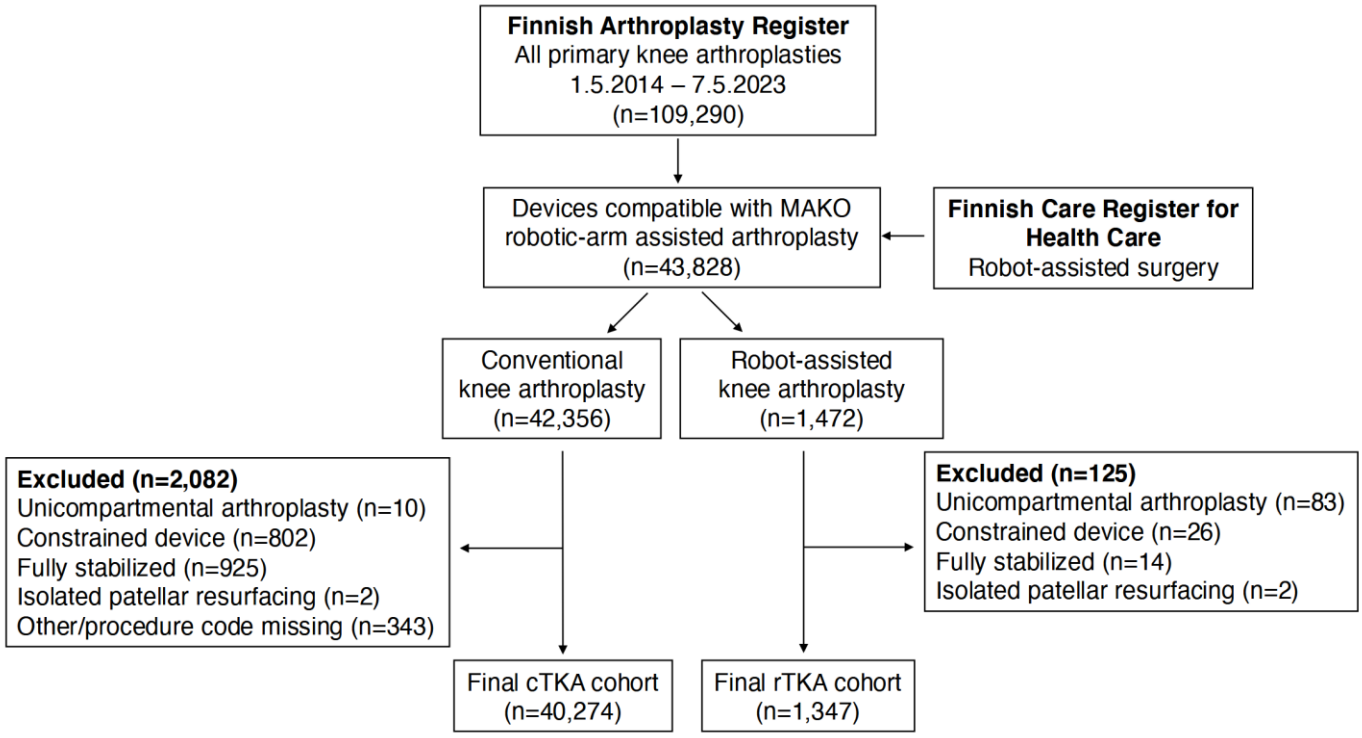

Figure 1. Patient flow chart

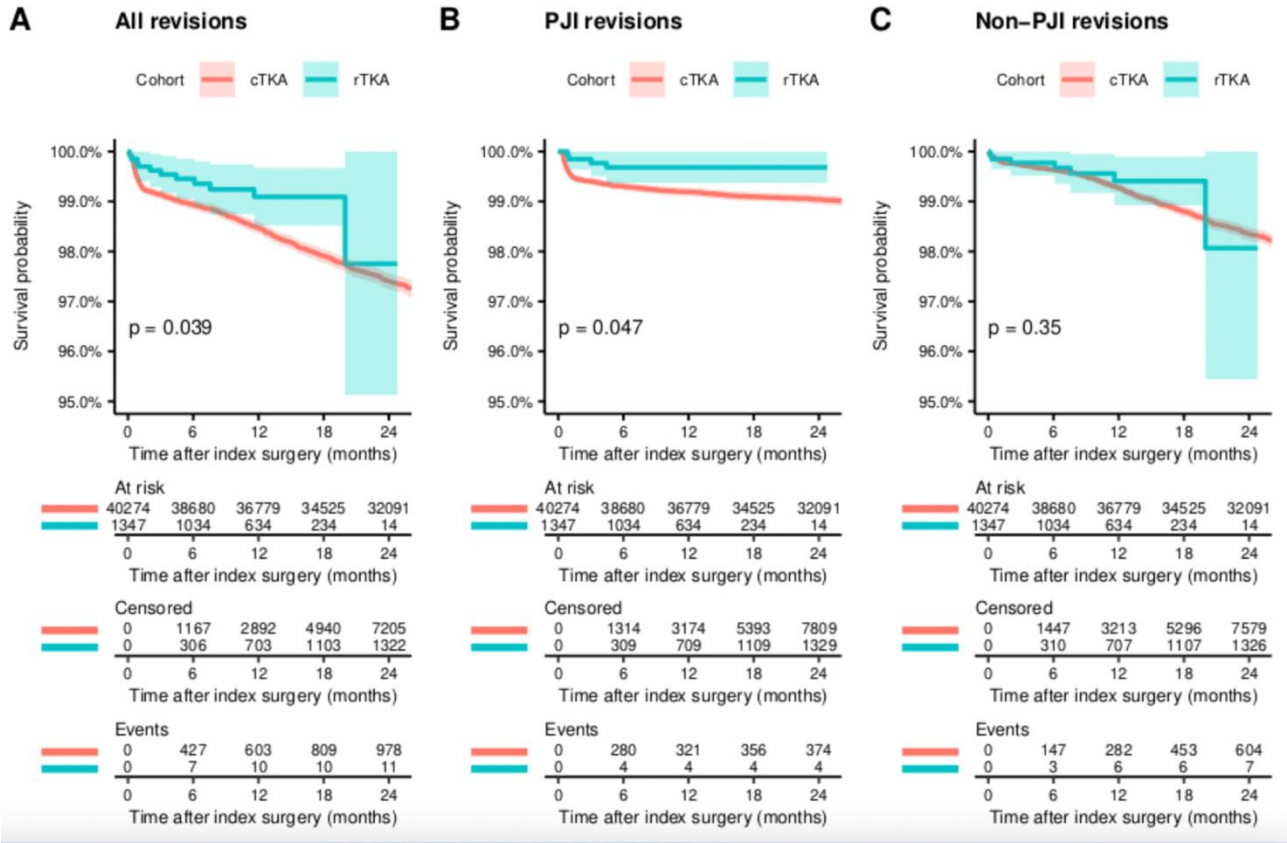

Figure 2. Kaplan-Meier curves for A) overall revision-free implant survival and B) revision due to periprosthetic joint infection (PJI) or C) revision due to other causes than PJI as an endpoint in robot-assisted total knee arthroplasty (rTKA) and non-robot-assisted total knee arthroplasty (cTKA) cohorts.