Does changes in unicompartmental knee arthroplasty practice pattern influence reasons for revision?

A study of 9,639 cases

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Aims
The aim of this study was to describe the pattern of revision indications for unicompartmental knee arthroplasty (UKA) and total knee arthroplasty (TKA) and any change to this pattern for UKA patients over the last 20 years, and to investigate potential associations to changes in surgical practice over time.

Methods
All primary knee arthroplasty surgeries performed due to primary osteoarthritis and their revisions reported to the Danish Knee Arthroplasty Register from 1997 to 2017 were included. Complex surgeries were excluded. The data was linked to the National Patient Register and the Civil Registration System for comorbidity, mortality, and emigration status. TKAs were propensity score matched 4:1 to UKAs. Revision risks were compared using competing risk Cox proportional hazard regression with a shared γ frailty component.

Results
Aseptic loosening (loosening) was the most common revision indication for both UKA (26.7%) and TKA (29.5%). Pain and disease progression accounted for 54.6% of the remaining UKA revisions. Infections and instability accounted for 56.1% of the remaining TKA revision. The incidence of revision due to loosening or pain decreased over the last decade, being the second and third least common indications in 2017. There was a decrease associated with fixation method for pain (hazard ratio (HR) 0.40; 95% confidence interval (CI) 0.17 to 0.94) and loosening (HR 0.29; 95% CI 0.10 to 0.81) for cementless compared to cemented, and units UKA usage for pain (HR 0.67, 95% CI 0.50 to 0.91), and loosening (HR 0.51; 95% CI 0.37 to 0.70) for high usage.

Conclusion
The overall revision patterns for UKA and TKA for the last 20 years are comparable to previous published patterns. We found large changes to UKA revision patterns in the last decade, and with the current surgical practice, revision due to pain or loosening are significantly less likely.

Take home message
- Historically, unicompartmental knee arthroplasty (UKA) patients are significantly less likely to get revised due to infection than total knee arthroplasty, but more likely to get revised due to pain or aseptic loosening.

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- The number of UKA revisions performed due to pain and aseptic loosening has declined as UKA usage has increased nationally.
- UKA revision due to pain or loosening is significantly less likely at high UKA usage centres or if the primary implant used cementless fixation.

Introduction

For patients with end-stage osteoarthritis (OA) of the knee, an arthroplasty is the next step once conservative treatments have failed. For between 25% and 47% of these patients, their wear pattern is anteromedial, making them eligible for both medial unicompartmental knee arthroplasty (UKA) and total knee arthroplasty (TKA).[1,2] Internationally, only approximately 10% of primary knee arthroplasties are UKAs.[3-5] UKA has been shown to provide better function, lower mortality, faster recovery, fewer complications, and readmissions and to be more cost-effective than TKA, but it has higher revision risks.[6-10]

Using revision to compare the outcome of TKA and UKA surgery we need to keep in mind the UKA surgery has a lower revision threshold compared to TKA surgeries.[11,12] Further, there are differences is in the revision indications, with UKA patients largely being revised for unspecific indications such as pain and loosening, whereas TKA patients are commonly revised due to specific indications such as infections.[7,13]

Historically, the UKA was up to six-times more likely to get revised compared to TKA;[14] however, when using appropriate guidelines for practice and patient selection, this difference is significantly reduced.[15,16] In the last two decades, there has been changes to fixation, patient selection, and surgical practice, changes which are all associated with lower risk of revision.[15-19] However, little is known about the mechanisms behind the reduced revision risk. UKA usage rates is commonly interpreted as surgeons adhering to current guidelines for patient selection,[15] and cementless fixation was introduced to reduce the risk of physiological radiolucencies. Thus, the changes should reduce the risk of inappropriate revisions.[20,21]

We have seen an increase in UKA usage nationally in the last decade, and it currently accounts for more than 20% of all primary knee arthroplasties.[22] Regardless of the increased UKA usage, we are seeing a decrease in UKA revision risks.[22,23] Thus, the aim is to improve our understanding of which factors are likely to contribute to this overall decrease in revisions despite the increase in use, through investigating changes to revision indication patterns and their association to surgical practice changes over time. Such information would improve our understanding of how to choose the right implant for the right patient.

Methods

Data

All primary UKA and TKA surgeries due to primary OA and any revisions of these from 1997 to 4 December 2017 reported to the Danish Knee Arthroplasty Register (DKR) were included. Complex primary surgeries (bone grafts or component supplements) and patients who could not be linked to the Central Patient Register (CPR), in order to obtain mortality and emigration status, were excluded. The data was linked to the National Patient Register (NPR) to obtain comorbidities. The Danish Health Data Authority performed the data link.

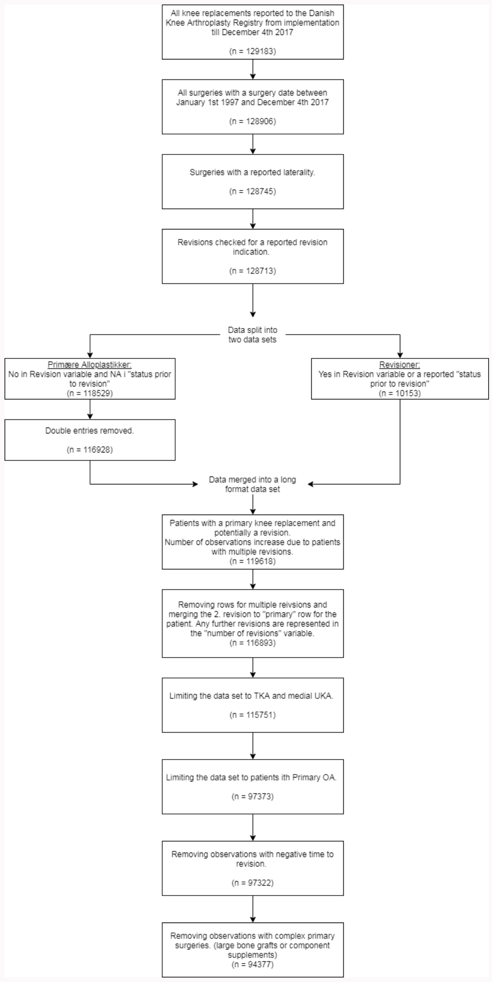

Fig. 1
Patient selection.[23]

Surgeons are able to choose multiple revision indications.[22] To determine the main revision indications, the first author (MM) and senior author (AT) went through all 105 indication combinations determining a main indication for each. To validate the consistency of these choices, a hierarchy was built (Supplementary table i). Surgeons can also choose "other indications" and write the indication freehand. These were reclassified into an existing category if the text indisputably fit a category. If they did not fit a category, or there was a level of uncertainty as to the correct category they were treated as "other indications" in the analysis, but categorized based on a best guess descriptively (Supplementary table ii).

The cohort has previously been published.[23]

Statistical analysis

The established cohort was propensity score matched one UKA procedure to four TKA procedures using sex, age, weight, date of surgery, Charlson Comorbidity Index (CCI),[24] alignment, and unit type to calculate each patient's propensity score through logistic regression. Sex, age, weight, date of surgery, alignment, and unit type were reported to DKR. CCIs were calculated using the NPR data, using ICD-8 and ICD-10 codes[25] for every inpatient (from 1977) and outpatient (from 1994)

Table I. Patient characteristics, before (unmatched) and after (matched) propensity score matching. Standardized mean difference of 0.1 or less indicated balance between groups. This table has previously been published.[23]

Variable	Unmatched data			1:4 matched data		
	UKA	TKA	SMD	UKA	TKA	SMD
Total	9,639	84,738		9,639	38,556	
Male sex, n (%)	4,320 (44.8)	31,418 (37.1)	0.158	4,320 (44.8)	17,241 (44.7)	0.002
Age at surgery, yrs (range)	65.7 (40.1 to 97.6)	69.5 (40.1 to 96.2)	0.448	65.7 (40.1 to 97.6)	66.2 (40.1 to 93.6)	0.084
Weight, kg (range)	84.7 (45 to 200)	85.1 (45 to 200)	0.020	84.7 (45 to 200)	85.1 (45 to 200)	0.020
Date of surgery, n (%)			0.368			0.125
1997 to 2001	194 (2.0)	7,131 (8.4)		194 (2.0)	1,204 (3.1)	
2002 to 2006	1,405 (14.6)	15,648 (18.5)		1,405 (14.6)	4,287 (11.1)	
2007 to 2011	2,947 (30.6)	28,685 (33.9)		2,947 (30.6)	12,605 (32.7)	
2012 to 2017	5,093 (52.8)	33,274 (39.3)		5,093 (52.8)	20,460 (53.1)	
Alignment, n (%)			0.625			0.018
< 0 to 4° (varus)	7,784 (80.8)	49,306 (58.2)		7,784 (80.8)	30,905 (80.5)	
5 to 10° (neutral)	1,704 (17.7)	23,240 (27.4)		1,704 (17.7)	6,986 (80.5)	
> 11° (valgus)	35 (0.4)	11058 (13.0)		35 (0.4)	150 (0.4)	
Not examined	116 (1.2)	1,134 (1.3)		116 (1.2)	515 (1.3)	
CCI			0.064			0.016
0: none	6120 (63.5)	51,583 (60.9)		6,120 (63.5)	24,252 (62.9)	
1 to 2: mild	2,094 (21.7)	19,763 (23.3)		2,094 (21.7)	8,441 (21.9)	
3 to 4: moderate	1,163 (12.1)	10,465 (12.3)		1,163 (12.1)	4,739 (12.3)	
> 5: severe	262 (2.7)	2,927 (3.5)		262 (2.7)	1,124 (2.9)	
Unit type (public)	8,791 (91.2)	7,7921 (92.0)	0.027	8,791 (91.2)	35,165 (91.2)	< 0.001
Non-matching variables, n (%)						
Study knee, left	4,942 (51.3)	40,856 (48.2)		4,942 (51.3)	19,211 (49.8)	
AKSS (f)	57.5 (0 to 100)	49.0 (0 to 100)		57.5 (0 to 100)	51.5 (0 to 100)	
Usage rate, n (%)						
None, 0%	0 (0.0)	26,702 (31.5)		0 (0.0)	11518 (29.9)	
Low, 0 to 20%	5,033 (52.2)	48,630 (57.4)		5,033 (52.2)	22,179 (57.5)	
High > 20%	4,606 (47.8)	9,406 (11.1)		4,606 (47.8)	4,859 (12.6)	
Surgical volume, n (%)						
None, 0	0 (0.0)	26,702 (31.5)		0 (0.0)	11,518 (29.9)	
Low, 0 to 51	4,446 (46.1)	4,277 (50.5)		4,446 (46.1)	18,838 (48.9)	
High, > 52	4,606 (47.8)	15,264 (18.0)		4,606 (47.8)	8,200 (21.3)	
Fixation, n (%)						
Cemented	7,153 (74.2)	63,043 (74.4)		7,153 (74.2)	27,675 (71.8)	
Cementless	2,393 (24.8)	5,823 (6.9)		2,393 (24.8)	2,735 (7.1)	
Hybrid	47 (0.5)	15,576 (18.4)		47 (0.5)	8,015 (20.8)	
N/A	46 (0.5)	296 (0.3)		46 (0.5)	131 (0.3)	

AKSS (f), American Knee Society Score (function); CCI, Charlson Comorbidity Index; N/A, not applicable; SMD, standardized mean difference; TKA, total knee arthroplasty; UKA, unicompartmental knee arthroplasty.

Table II. Ranked revision indication and hazard ratios for total knee arthroplasty versus unicompartmental knee arthroplasty.

Indication	TKA		UKA		HR (95% CI)	p-value*
	Rank	N (%)	Rank	N (%)		
Primary surgeries		30,556		9,639		
Loosening	1	553 (1.8)	1	270 (2.8)	2.08 (1.79 to 2.41)	< 0.0001
Infection	2	405 (1.3)	6	47 (0.5)	0.53 (0.39 to 0.72)	< 0.0001
Instability	3	335 (1.1)	5	81 (0.8)	1.05 (0.82 to 1.35)	0.664
Pain	4	195 (0.7)	2	268 (2.8)	5.92 (4.90 to 7.14)	< 0.0001
Other	5	142 (0.5)	4	129 (1.3)	3.89 (3.05 to 4.96)	< 0.0001
Secondary patella	6	102 (0.3)	10	2 (0.02)	0.08 (0.02 to 0.33)	0.0005
Unknown	7	65 (0.2)	7	43 (0.5)	2.80 (1.89 to 4.14)	< 0.0001
Tibia bearing failure	8	43 (0.1)	8	31 (0.3)	3.15 (1.97 to 5.04)	< 0.0001
Patella bearing failure	9	26 (0.1)	9	3 (0.03)	0.50 (0.15 to 1.67)	0.26
Osteoarthritis progression	10	7 (0.02)	3	136 (1.4)	85.0 (39.68 to 182.2)	< 0.0001

*Statistical analysis with a competing risk Cox proportional hazard regression with a shared γ frailty component.
CI, confidence interval; HR, hazard ratio.

Table III. Median survival time by revision indication for total knee arthroplasty and unicompartmental knee arthroplasty.

Indication	Median survival time, years (IQR)	
	TKA	UKA
Infection	0.65 (0.10 to 2.06)	0.64 (0.11 to 2.60)
Loosening	2.50 (1.42 to 5.79)	2.48 (1.24 to 5.03)
Tibia bearing failure	5.79 (1.87 to 12.10)	2.75 (0.46 to 7.23)
Patella bearing failure	2.58 (1.37 to 5.55)	3.39 (1.80 to 6.34)
Osteoarthritis progression	2.15 (1.00 to 6.39)	6.02 (2.87 to 8.56)
Instability	1.53 (0.94 to 2.60)	1.78 (0.74 to 3.81)
Pain	1.49 (1.02 to 2.38)	1.73 (1.04 to 3.51)
Secondary patella	1.46 (0.94 to 2.68)	1.96 (1.20 to 2.71)
Other	0.84 (0.23 to 1.82)	0.79 (0.27 to 2.69)
Unknown	1.50 (0.93 to 3.39)	2.35 (1.24 to 5.30)
All indications	1.55 (0.78 to 3.35)	2.05 (0.95 to 5.08)

IQR, interquartile range; TKA, total knee arthroplasty; UKA, unicompartmental knee arthroplasty.

visit.[26] Calculating a ten-year CCI, meaning any diagnoses from the ten years prior to the date of surgery, were included in the comorbidity index.

We propensity score matched to address the lack of randomization. It calculates a score based on known confounders' effect on the exposure using logistic regression. The nearest neighbor method was used for matching, a proximity search method.[27] As propensity score matching is unable to handle missingness for the confounders, multiple imputation was employed to calculate missing values for weight (predictive mean matching) and alignment (polytomous logistic regression). Sensitivity analysis was done descriptively and assessed by three of the authors individually before matching. Balance of the matching was determined using standardized mean difference (SMD), with an SMD > 0.1 indicated imbalance.[28] Unbalanced confounders were tested for significanse of the diffence using independent-samples *t*-test.

Survival analyses were done using competing risk Cox proportional hazard regression with a shared γ frailty component, where each revision indication was investigated as the outcome keeping all other revision indications and mortality as competing risks. Violations of the proportional hazard assumption were examined using Schoenfeld's residuals and effect modifications from covariates were tested using likelihood ratio tests.[29] The shared γ frailty component was added to account for dependence of bilateral cases.[30]

Usage rates were calculated per calendar year on a unit level. High usage was defined as 20% or more of all primary knee arthroplasty being UKA, low < 20% or none 0%. Thus, units could switch between categories from year to year. The patients were assigned the category the revision unit had the year of their surgery.[19] Statistical significance level was defined as $p < 0.01$. All statistics were calculated using R version 4.0.3 (R Foundation for Statistical Computing, Austria).

Results

The registry cohort included 129,183 primary and revision knee arthroplasty surgeries. After applying the inclusion and exclusion criteria the cohort composed of 94,377 primary knee surgeries (Figure 1).

Propensity score matching

Multiple imputations for weight and alignment were concluded to be missing at random when examined over time, and in correlation with other explanatory variables. The propensity score matching resulted in a cohort of 48,195 knee arthroplasties, insuring balance for all matching variables except date of surgery (SMD 0.125) (Table I).

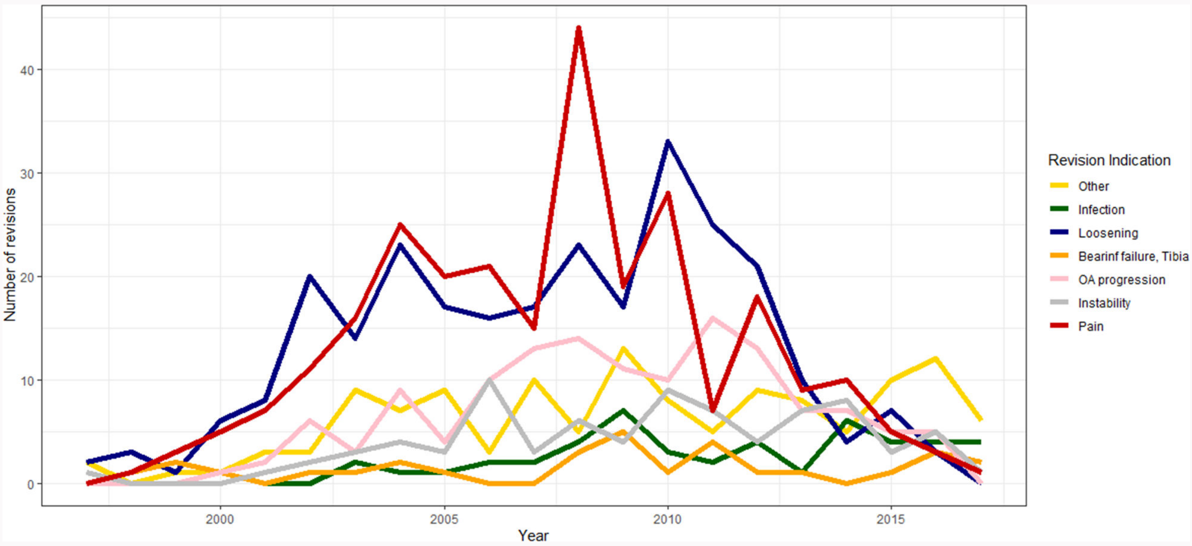

Fig. 2

Frequency of unicompartmental knee arthroplasty revisions by revision indication.

Table IV. Ranked revision indications and hazard ratios for cemented versus cementless unicompartmental knee arthroplasty.

Indication	Cemented		Cementless		HR (95% CI)
	Rank	N (%)	Rank	N (%)	
Primary surgeries, n		8,546		1,000	
All indications		2,329 (27.3)		64 (6.4)	0.16 (0.01 to 1.03)
Loosening	1	264 (3.1)	7	4 (0.4)	0.29 (0.10 to 0.81)
Pain	2	260 (3.0)	5	6 (0.6)	0.40 (0.17 to 0.94)
Osteoarthritis progression	3	128 (1.5)	4	7 (0.7)	0.82 (0.36 to 2.00)
Other	4	105 (1.2)	1	23 (2.3)	1.43 (0.74 to 2.78)
Instability	5	71 (0.8)	2	9 (0.9)	1.13 (0.50 to 2.53)
Unknown	6	40 (0.5)	8	1 (0.1)	0.79 (0.09 to 7.13)
Infection	7	38 (0.5)	2	9 (0.9)	1.03 (0.09 to 12.00)
Tibia bearing failure	8	25 (0.3)	6	5 (0.5)	2.63 (0.51 to 13.53)
Patellia bearing failure	9	3 (0.04)	9	0 (0.0)	N/A
Secondary patella	10	2 (0.02)	9	0 (0.0)	N/A

CI, confidence interval; HR, hazard ratio.

Revision indication patterns and revision timing for UKA and TKA

Of all revisions 629 UKAs (62.3%) and 972 TKAs (52.9%) were performed at the same unit as the primary surgery. Loosening is the most common revision indication for both treatment options, after which TKAs were most at risk of revision due to infection or instability. UKAs were significantly less likely to get revised due to infection (hazard ratio (HR) 0.53; 95% confidence interval (CI) 0.39 to 0.72; $p < 0.0001$) but more likely to get revised due to pain (Table II).

UKAs were revised six months later than TKAs ($p < 0.0001$, independent-samples *t*-test) (Table III). Pain and loosening are the most common revision indications for UKAs (Table II), though from 2010 both have seen a fall in incidence and are now among the three least common revision indications for UKA (Figure 2).

Failure patterns for UKA depending on fixation mode and usage rates

The failure patters differed depending on the type of fixation, with significant differences for loosening (HR 0.29; 95% CI 0.10 to 0.81) and pain (HR 0.40; 95% CI 0.17 to 0.94). Being the most common revision indications for cemented UKAs accounting for 66%, it accounted for less than 16% of all cementless UKA revisions (Table IV). Cementless UKAs had a non-significant higher incidence of revisions due to instability and "other indications".

Table V. Ranked revision indication for high, low and none unicompartmental knee arthroplasty usage of the revision unit. Hazard ratios compare no and low usage to high usage units.

Indication	None		Low		High		HR (95% CI)
	Rank	N (%)	Rank	N (%)	Rank	N (%)	
Primary surgeries		0		5,033		4,606	
All indications		125 (1.30)		598 (6.20)		285 (2.96)	0.78 (0.68 to 0.90)
Loosening	1	45 (0.47)	2	172 (1.78)	3	53 (0.55)	0.51 (0.37 to 0.70)
Pain	2	32 (0.33)	1	179 (1.86)	2	56 (0.58)	0.67 (0.50 to 0.91)
Osteoarthritis progression	3	18 (0.19)	3	72 (0.75)	4	46 (0.48)	0.74 (0.51 to 1.08)
Other	6	4 (0.04)	4	60 (0.62)	1	65 (0.67)	1.86 (0.96 to 3.61)
Instability	5	9 (0.09)	5	44 (0.46)	5	28 (0.29)	0.90 (0.55 to 1.49)
Unknown	4	13 (0.13)	7	18 (0.19)	6	12 (0.12)	0.87 (0.43 to 1.75)
Infection	7	2 (0.02)	6	33 (0.34)	6	12 (0.12)	0.36 (0.11 to 1.18)
Tibia bearing failure	7	2 (0.02)	8	16 (0.17)	6	12 (0.12)	1.24 (0.54 to 2.85)
Patellia bearing failure	9	0 (0.00)	9	2 (0.02)	9	1 (0.01)	N/A
Secondary patella	9	0 (0.00)	9	2 (0.02)	10	0 (0.0)	N/A

CI, confidence interval; HR, hazard ratio; N/A, not applicable.

Usage rates showed significant difference between the no or low usage units and high usage units regarding pain and loosening (Table V). Thus, UKA patients revised at a high usage unit had significantly lower risk of revision due to loosening (HR 0.51; 95% CI 0.37 to 0.70) or pain (HR 0.67; 95% CI 0.50 to 0.91). Again, the "other indications" were a more common indication at a high usage unit, but with no significant increased risk compared to no or low usage units. UKA patients treated at high usage units had a significantly lower all cause revision risk (HR 0.78; 95% CI 0.68 to 0.90). The "other indications" category predominantly contained OA progressions, bearing dislocations and periprosthetic fractures (Supplementary table ii).

Discussion

Overall, loosening is the most common revision indication in both UKA and TKA, but the pattern differs between the two treatments on all other indications. The pattern is similar to that described by Liddle et al[7] in their registry study from 2014 (Table II).

We found TKA patients to have twice the risk of revision due to infection compared to UKA patients, even with the overall higher revision risk for UKA patients (Table II). These periprosthetic joint infections have been shown to have a 90-day mortality of 1.2% compared to 0.6% for revision TKAs overall, and they have a higher risk of re-revisions, including two-stage revisions.[31] Thus, revisions due to infection pose a greater risk for the patient and a larger burden on the healthcare system, which needs to be considered when using revision risk to compare TKA and UKA.

The overall higher risk of revision for UKA patients is primarily due to higher risk of loosening, pain, and OA progression (Table II). However, looking at the pattern over time we found large decreases in the number of revisions due to pain and loosening, whereas the remaining indications largely remain stable over time, except for the "other" indication (Figure 2). The literature shows an association between revision risk and surgical load, the usage of UKA versus TKA and the fixation mode exist.[16,17] With tests on this cohort, we found a similar association.[23]

Loosening and pain are the common factors throughout our analyses. As mentioned earlier, we regard these as unspecific revision indications, and they are likely to be done on inappropriate indications.[20] One such is unexplained pain, and there is a consensus to not revise TKA because it is unlikely to improve the symptom.[32] The same is true for UKA, though there is less evidence.[13,33] Inappropriate revisions for loosening can occur by misinterpretation of physiological radiolucencies often in connection with unexplained pain.[20,21] Physiological radiolucencies are seen in up to 50% of all cemented UKAs.[20] Thus, a reason to switch to cementless fixation is lower risk physiological radiolucencies, with the tradeoff of a potential increase in periprosthetic fractures.[17,34] Cementless fixation reduced the revision risks due to loosening or pain significantly but had a trend towards higher likeliness of revisions with "other" as the indication (Table IV). In all, 70.7% of the "other" category was composed of OA progression, bearing dislocations and periprosthetic fractures (Supplementary table ii). Bearing dislocations and periprosthetic fractures are two indications, which has previously been linked to the introduction of the cementless UKA.[17,35] The increases in bearing dislocations are most likely due to more than 90% of cementless UKAs in the cohort being the mobile-bearing Phase 3 Oxford partial knee (Zimmer Biomet, USA).

The study's strengths are the large cohort from a registry with a consistently high completeness for both primary and revision surgeries. The large cohort and available comorbidity data makes it possible for us to propensity score match controls (TKA) to every available UKA procedure reducing confounding by indications.[36] The registry has consistently had a completeness above 90% for both primary and revision surgery since 2007 which limits the amount of attrition bias.[22] The 20-year data collection permits us to look at changes in revision indication pattern over time and gain an understanding of what may coincide with these changes. In the statistical approach we addressed dependent observations by adding a random effect to the cox model, limiting attrition bias considerably.[30] Furthermoree, we treated the independent revision indications and mortality as competing risks.[37]

The most important limitation is the lack of randomization. As mentioned in the strengths, it is addressed by propensity score matching. However, a level of residual bias is expected from both known and unknown confounders.[38] The significant association of unit UKA usage and fixation mode to revision indication patterns cannot be labeled as causative, as we are working on registry data whose original purpose is safety monitoring, further it is possible that more experienced UKA surgeons are clustered at high usage units and tend to use the cementless implant, making their experience the true reason for the difference. The indication categories available to the surgeons represent another limitation.[22] We have a large proportion of revisions marked as "other", especially for the cementless UKAs (Table IV). The "other" category contained a large proportion of bearing dislocations and periprosthetic fractures, for which there are no available categories in the registry form (Ssupplementary table i), making underestimation of these indications a genuine concern. Lastly, an unknown proportion of periprosthetic fractures are treated without revisions, and thus not reported to the registry. The New Zealand Joint Registry report a frequency of 0.2% of UKAs presenting with a periprosthetic fracture.[5] Thus, we need to keep this increased risk of fractures in mind when concluding on the benefits of cementless fixation.[17]

In conclusion, we found a large decrease in revisions due to aseptic loosening and pain starting in 2010 (Table II), coinciding with an overall decrease in UKA revision risk in this cohort.[23] It also coincided with the implementation of cementless fixation and a large increase in high usage units,[19,23] for which we found a strong association to aseptic loosening and pain as revision indications (Tables IV and V). Combining this our interpretation is that the increased usage and implementation of cementless fixation has eliminated a large proportion of the UKA revisions done on inappropriate indications.[13]

Lastly, with the introduction of cementless fixation and the increase in high usage units, we observed a relative increase in bearing dislocations and periprosthetic fractures for which there are no available categories in the registry. Thus, we urge the registry to include these as revision indication categories in the future.

Supplementary material

Tables showing hierarchy for determining main revision indications; and revision indications for unicompartmental knee arthroplasty, when revision indication "other" was chosen, and they could not be reclassified.

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Data sharing

The datasets generated and analyzed in the current study are not publicly available due to data protection regulations. Access to data is limited to the researchers who have obtained permission for data processing. Further inquiries can be made to the corresponding author.

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