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Primary Knee

Association Between Surface Modifications for Biologic Fixation and Aseptic Loosening of Uncemented Total Knee Arthroplasties

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Background: Various surface modifications are used in uncemented total knee arthroplasties (TKAs) to enhance bony ingrowth and longevity of implants. This study aimed to identify which surface modifications are used, whether they are associated with different revision rates for aseptic loosening, and which are underperforming compared to cemented implants.

Methods: Data on all cemented and uncemented TKAs used between 2007 and 2021 were obtained from the Dutch Arthroplasty Register. Uncemented TKAs were divided into groups based on their surface modifications. Revision rates for aseptic loosening and major revisions were compared between groups. Kaplan-Meier, Competing-Risk, Log-rank tests, and Cox regression analyses were used. In total, 235,500 cemented and 10,749 uncemented primary TKAs were included. The different uncemented TKA groups included the following: 1,140 porous-hydroxyapatite (HA); 8,450 Porous-uncoated; 702 Grit-blasted-uncoated; and 172 Grit-blasted-Titanium-nitride (TiN) implants.

Results: The 10-year revision rates for aseptic loosening and major revision of the cemented TKAs were 1.3 and 3.1%, and for uncemented TKAs 0.2 and 2.3% (porous-HA), 1.3 and 2.9% (porous-uncoated), 2.8 and 4.0% (grit-blasted-uncoated), and 7.9% and 17.4% (grit-blasted-TiN), respectively. Both type of revision rates varied significantly between the uncemented groups (log-rank tests, $P < .001$, $P < .001$). All grit-blasted implants had a significantly higher risk of aseptic loosening ($P < .01$), and porous-uncoated implants had a significantly lower risk of aseptic loosening than cemented implants ($P = .03$) after 10 years.

Conclusion: There were 4 main uncemented surface modifications identified, with different revision rates for aseptic loosening. Implants with porous-HA and porous-uncoated had the best revision rates, at least equal to cemented TKAs. Grit-blasted implants with and without TiN underperformed, possibly due to the interaction of other factors.

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Total knee arthroplasty (TKA) used to be mainly done on elderly patients using implants that lasted mainly around 10 to 15 years. However, as TKA becomes more prevalent among younger patients who continue to engage in demanding activities after TKA, it is anticipated that there will be an increase in the number of revisions performed, particularly those occurring 10 to 15 years after the initial surgery [1]. Given the reports from national registries showing that aseptic loosening is the leading reason for late revision procedures, it is important to find ways to extend the life of prostheses to reduce the number of late revisions required [2–4].

In an effort to overcome this ambition, manufacturers have been developing their implants, with the most prominent advances made in modern uncemented implants. Studies of previously used, now outdated, uncemented TKA designs showed underperformance, resulting in a condemnation of cementless fixation by some researchers and clinicians. However, recent high-level evidence suggests that modern cementless implants show similar durability and outcomes to cement-fixated implants at a mean follow-up of 7 to 12 years [5–8]. The fixation of uncemented implants primarily focuses on improving osseointegration, which refers to the biological ingrowth process. This method eliminates the presence of cement wear particles associated with cemented TKA, which can lead to reduced instances of implant loosening and foreign body reactions [9–11]. Moreover, most modern uncemented TKAs have a modified surface or coating to improve the biological properties of the implant, such as promoting cell attachment, spreading, growth, and the formation of new bone tissue [12–14].

Although aseptic loosening is multifactorial in nature, it can roughly be classified as a result of an early lack of osseointegration, or a later failure of the implant-bone interface due to periprosthetic osteolysis. The theory that aseptic loosening is caused by a lack of osseointegration is supported by the association found between magnified early migration and late revision for aseptic loosening [15]. This was measured by Radiostereometric analyses (RSAs), which refers to a radiographic technique that allows 3-dimensional measurement of migration of prosthesis components over time. To test whether new implants are safe for patients, an implant's early migration pattern is often evaluated with RSA to benchmark against migration patterns of former implants. Previous studies utilizing RSA reported that the use of hydroxyapatite (HA) coating can improve early implant stabilization compared to non-HA-coated or cemented implants [16–19]. Although RSA can accurately measure differences in migration patterns, it is challenging to actually measure the variations in late revisions for aseptic loosening because the incidence is relatively low, and mainly occurs late in follow-up.

Therefore, the purpose of this study was to utilize the national arthroplasty register of the Netherlands, in order to investigate the following questions: (1) what are the prevalent surface modifications utilized in uncemented implants in the Netherlands? (2) are there any variations in the revision rates for aseptic loosening among uncemented implants with different surface modifications? (3) does any surface modification exhibit inferior performance in terms of revision for aseptic loosening when compared to cemented implants?

Material and Methods

Data Source

This observational study used routinely collected data from the Dutch Arthroplasty Register (Landelijke Registratie Orthopedische Implantaten [LROI]). The register collects data since 2007 and covers all Dutch hospitals since 2012, with overall completeness of collected data of 99% for primary TKAs and 98% for revision TKAs in 2020 [4]. Specifications of implant surface modifications are registered by scanning the product and batch numbers of implants during TKA and reported according to the names used in the international prosthesis library of the International Society of Arthroplasty Registers [20]. Patient informed consent is perceived by the use of an opt-out system. Encrypted social security numbers are linked to the Dutch national insurance database, to connect primary and revision TKAs and identify deaths [4].

Patient Selection

All patients who underwent a fully cemented or uncemented TKA for osteoarthritis in the Netherlands between 2007 and 2021 were eligible for inclusion. Patients were excluded in case implant batch or product information was missing; revision components were used; cemented implant brands that had not also been used uncemented; the number of implants per brand was less than 50; or when 1 component of an implant had a different surface modification than the other component. The flowchart of in-and exclusion is presented in Figure 1. After inclusion, uncemented implants were categorized into groups, based on the matching surface modification of the femoral and tibial components of every implant. For each procedure, the following characteristics were extracted: age, gender, body mass index (BMI), Charnley classification (A, B1, B2, and C), American Society of Anesthesiologists (ASA) grade (I, II, III to IV), smoking status, previous knee surgeries, surgical approach (medial parapatellar or other), bearing type (fixed or mobile), hospital (anonymously coded) and revision information. Data on BMI, smoking status, and Charnley classification had only been registered since 2014.

Study Population

A total of 245,971 primary TKAs were included in this study, comprising 235,500 cemented and 10,471 uncemented implants. In total, 6 different surface modifications could be distinguished. After excluding uncemented implants of which the femoral and tibial components had different surface modifications (Fig. 1), 4 groups were included as follows: (1) porous metal with a HA coating (n = 1,140); (2) porous metal without coating (n = 8,450); (3) grit-blasted metal without coating (n = 702); and (4) grit-blasted metal with Titanium nitride (TiN) coating (n = 179). Uncemented implants that were not included in the analysis were implants with a porous-TiN or grit-blasted-polymethylmethacrylate surface modifications. Uncemented implants with trabecular metal were not included due to a low number of TKAs. Demographic details and clinical characteristics per group are presented in Table 1. The populations' overall median follow-up was 5.1 years (Interquartile range 2.6 to 8.2, range 0 to 14). The groups differed in the distribution of fixed and mobile bearings, the variety of hospitals, the variety of implant designs, and the median follow-up.

Outcome Measures

The primary outcome in this study was the 5 and 10-year revision rate for aseptic loosening per group. Revision is defined as the removal or exchange of at least 1 component due to aseptic loosening. The secondary outcome was the major revision rate at 5 and 10 years. A major revision was defined as the removal or exchange of at least the femoral or tibial component for any reason. Major revision as an outcome measure was used to provide a crude estimation of the internal validity regarding the primary outcome. It was proposed that surface modification of implant materials may only impact osseointegration, and thus the rate of aseptic

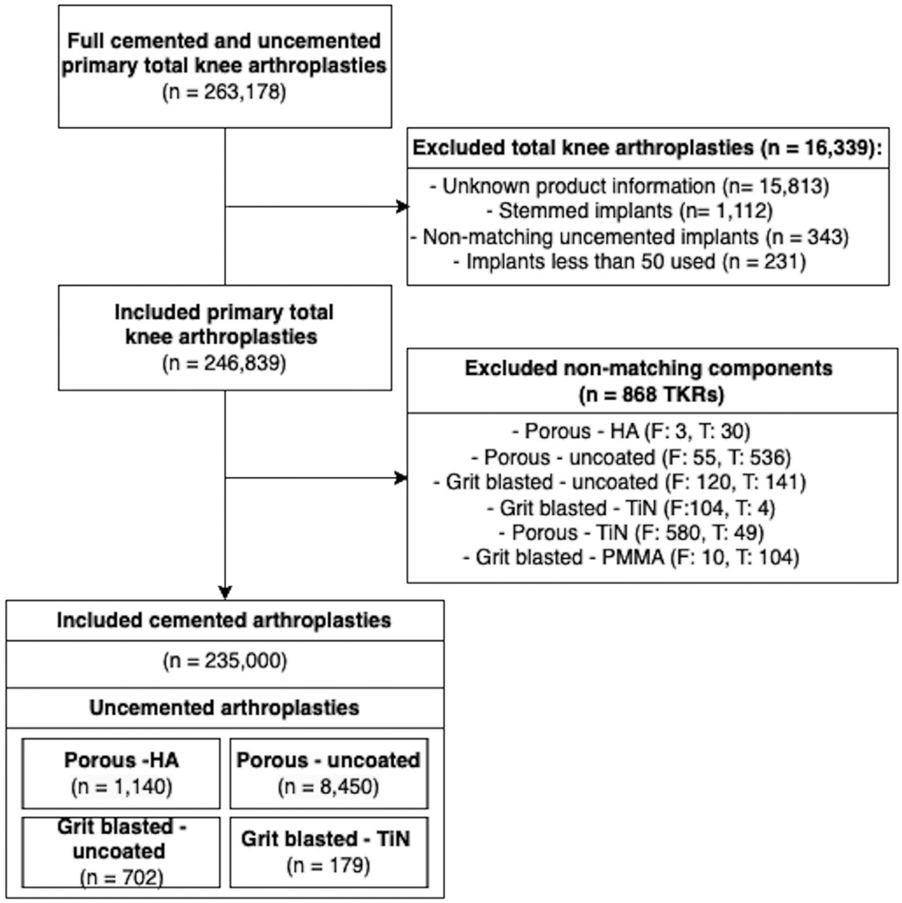

Fig. 1. Flow chart of in-and exclusion, and creation of groups. TKA, total knee arthroplasty; HA, Hydroxyapatite; TiN, Titanium-nitride; F, Femoral component; T, Tibial component; PMMA, Polymethylmethacrylate.

loosening, not other reasons of revision. If a specific group exhibits a significantly higher rate of major revisions compared to other groups, regardless of whether there is an increased rate of revisions due to aseptic loosening, it suggests that factors beyond surface modification might be contributing to performance of that particular group.

Data Analyses

Baseline characteristics are presented as means and SDs, medians and Interquartile ranges, or frequencies and percentages. Kaplan-Meier (KM) and competing risk (Supplementary File) analyses were performed to calculate the revision rate per group for aseptic loosening and major revision after 5- and 10-year follow-up. Patients were censored from KM analyses in case they died before the end of the study follow-up (January 1, 2021). Competing-risk analyses were also performed since the proportion of patients experiencing the competing event (death) was equal to or greater than those experiencing the outcome of interest (revision) [21]. Implant revision probability was reported with 95% CIs. The impact of the surface modification on the revision rate was explored by plotting KM curves for all groups. Log-rank tests were performed to assess if there were differences in revision rates among the uncemented surface modification groups. In case of a group with a substantially high major revision rate, a KM curve for different reasons for revisions of that group was plotted, to assist in identifying whether there are additional factors that have contributed to the outcome of the group. Additionally, crude and multivariate Cox proportional hazard models were used to compare the likelihood of revision with reference to the cemented group. Since some groups contained only fixed or mobile bearings, the Hazard Ratios (HRs) of each group were stratified by bearing mobility. HRs were calculated with 95% CIs and adjustment for age, gender, ASA classification, and previous knee operations was, like in other LROI studies, performed [22]. As data on smoking status, BMI, and Charnley classification were only available after 2014, sensitivity analyses were performed to assess the confounding effects of these variables. All statistical analyses were performed using IBM statistical Package for the Social Sciences (SPSS) version 26.0 (IBM Corp.) A P value < .05 was considered statistically significant.

Results

Revision Rate for Aseptic Loosening

Overall, a total of 121 uncemented implants were revised for aseptic loosening of at least 1 component, including 24 (19.8%) femoral and 112 (92.6%) tibial components. The mean cumulative revision rates varied among the groups after 10 years, including the; porous-HA group (0.2% [95% CI 0.0 to 0.4]); porous-uncoated group; (1.3% [95% CI 1.0 to 1.6]); grit-blasted-uncoated group (2.8% [95% CI 1.3 to 4.3]) and grit-blasted-TiN group (7.9% [95% CI 3.5 to 12.3]). All mean cumulative revision rates at 5 and 10 years are presented in Table 2 and Figure 2. The results of KM analyses were similar to competing-risk analyses (Supplementary File, Table 2b). Revision rates varied significantly between the

Table 1
Demographic Details and Clinical Characteristics of Included Population.

	Prosthesis Type				
	Cemented	Uncemented			
		Porous-HA	Porous-Uncoated	Grit-Blasted-Uncoated	Grit-Blasted-TiN
Knees, n	235,500	1,140	8,450	702	179
Median follow-up, y (IQR)	5.5 (2.6 to 8.1)	4.8 (2.8 to 7.8)	6.6 (3.1 to 9.6)	7.2 (3.8 to 9.6)	8.7 (4.5 to 10.5)
Sex, n (%)					
Woman	152,853 (64.9)	744 (65.3)	5,478 (64.8)	474 (67.5)	85 (47.5)
Mean age, y (SD)	68.8 (9.2)	68.7 (9.3)	69.0 (9.3)	69.9 (9.1)	68.5 (11.1)
Mean BMI, (SD)[a]	29.8 (5.4)	29.0 (4.1)	29.5 (4.9)	29.8 (4.6)	n/a
Previous knee surgery, n (%)[b]	67,900 (28.8)	383 (33.6)	2,104 (24.9)	123 (17.5)	46 (25.7)
ASA grade, n (%)					
I	37,190 (15.8)	103 (9.0)	1,370 (16.2)	142 (20.2)	102 (57.0)
II	153,722 (65.3)	824 (72.3)	5,783 (68.4)	386 (55.0)	66 (36.9)
III to IV	39,784 (16.9)	211 (18.5)	1,130 (13.4)	100 (14.2)	10 (5.6)
Charnley classification, n (%)[c,a]					
A	56,571 (24.0)	257 (22.5)	1,650 (19.5)	129 (18.4)	n/a
B1	49,090 (20.8)	293 (25.7)	1,110 (13.1)	99 (14.1)	n/a
B2	30,680 (13.0)	155 (13.6)	831 (9.8)	43 (6.1)	n/a
C	4,361 (1.9)	6 (0.5)	179 (2.1)	7 (1.0)	n/a
Smoking, n (%)[a]					
Yes	131,645 (55.9)	81 (7.1)	382 (4.5)	16 (2.3)	n/a
No	12,119 (5.1)	691 (60.6)	3,547 (42.0)	280 (39.9)	n/a
Surgical approach, n (%)					
Medial parapatellar	231,657 (98.4)	1,103 (96.8)	8,240 (97.5)	639 (91.0)	178 (99.4)
Bearing type, n (%)					
Fixed	212,014 (90.0)	1,093 (95.9)	17 (0.2)	581(82.8)	0 (0.0)
Mobile	22,890 (9.7)	47 (4.1)	8,433 (99.8)	121 (17.2)	179 (100.0)
Performed in hospitals, n (%)	102 (98.1)	8 (7.7)	24 (23.1)	67 (64.4)	1 (1.0)
N of implant designs	34	8	3	13	2
Years in use (range)	2007 to 2020	2007 to 2020	2007 to 2020	2007 to 2020	2007 to 2013

Numbers do not add up to total due to missing data.
n, numbers, HA, hydroxyapatite; TiN, titanium nitride; ASA, American Society of Anesthesiologists; IQR, interquartile range; n/a, not applicable.
[a] Not registered before 2014.
[b] Previous surgeries defined as any surgical procedure (eg, meniscectomy, osteotomy, ACL reconstruction, osteosyntheses, synovectomy, arthroscopy, and patellar realignment).
[c] Charnley score: (A) only 1 affected knee joint, (B1) both knee joints affected, (B2) a knee prosthesis in the contralateral knee joint, and (C) multiple joints affected.

uncemented groups (log-rank test, $P < .001$). The revision rates for aseptic loosening of the porous-HA and porous-uncoated groups were the lowest 2 of the 4 groups. The grit-blasted TiN-coated implants had a higher revision rate for aseptic loosening than all other groups at every follow-up point. The grit-blasted-Tin coated group was the only group in which the ratio of revised femoral and tibial components was 1:1. The mean cumulative major revision rates of all groups after 5 and 10 years are presented in Table 3 and Figure 3. All groups, except the grit-blasted TiN coating group, had similar major revision rates and 95% CI. The cumulative major revision rate of the grit-blasted-TiN coated group was substantially higher than in all other groups at every follow-up moment (log-rank test, $P < .001$). The reasons for major revisions of the grit-blasted-TiN coated group are plotted in Figure 4, showing aseptic loosening and instability as the most prevalent reasons for major revision. The results of KM analyses were similar to competing-risk analyses (Supplementary File, Table 3b).

Underperforming Surface Modifications

The revision rates for aseptic loosening of the porous-HA and porous-uncoated groups were lower and equal to the revision rate

Table 2
Five- and Ten-Year Revision Rates by Kaplan-Meier Analysis for Aseptic Loosening of at Least 1 Component of the Total Knee Arthroplasty.

	Total, n	Events			KM Revision Rate, % (95% CI)	n at Risk
		Total, n	Femoral Components, n	Tibial Components, n		
5-year estimate						
Cemented TKA	235,500	1,373	291	1,269	0.8 (0.8 to 0.8)	120,079
Uncemented TKA						
Porous-HA	1,140	2	0	2	0.2 (0.0 to 0.4)	553
Porous-uncoated	8,450	85	10	82	1.2 (1.0 to 1.4)	5,194
Grit-blasted-uncoated	702	10	1	9	1.6 (0.6 to 2.6)	443
Grit-blasted-TiN	179	10	7	6	5.9 (2.4 to 9.4)	131
10-year estimate						
Cemented TKA	235,500	1,766	405	1,648	1.3 (1.2 to 1.4)	30,970
Uncemented TKA						
Porous-HA	1,140	2	0	2	0.2 (0.0 to 0.4)	118
Porous-uncoated	8,450	93	14	90	1.3 (1.0 to 1.6)	1,839
Grit-blasted-uncoated	702	14	2	12	2.8 (1.3 to 4.3)	172
Grit-blasted-TiN	179	12	8	8	7.9 (3.5 to 12.3)	53

n, number; KM, Kaplan-Meier; TKA, total knee arthroplasty; HA, hydroxyapatite; TiN, titanium nitride.

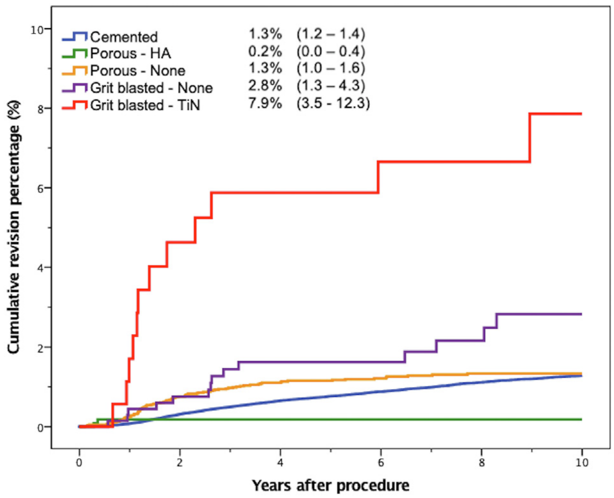

Fig. 2. Cumulative revision rates (95% CI) of cemented and uncemented implants stratified by their surface modifications, with as end point aseptic loosening of at least 1 component.

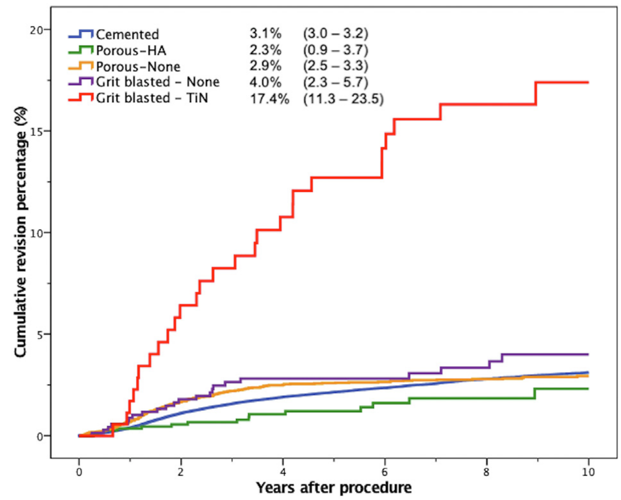

Fig. 3. Cumulative revision rates (95% CI) of cemented and uncemented implants stratified by their surface modifications, with as end point major revision.

of cemented implants at 10 years (Table 2, Fig. 2). Crude and adjusted HRs, stratified by bearing mobility, showed no significant difference in the likelihood of revision for aseptic loosening between cemented and porous metal HA-coated implants (P = .07) (Table 4). Porous metal-uncoated implants had a significantly lower likelihood of revision than cemented implants (0.76 [95% CI 0.60 to 0.98]) (P = .03). Patients with grit blasted-uncoated and grit blasted-TiN coated implants were 2.71 (95% CI 1.46 to 5.05) (P < .01) and 4.60 (95% CI 2.56 to 8.25) (P < .01) times more likely to undergo a revision than patients with cemented implants, respectively. Sensitivity analysis showed no differences in risk of revision after adding the covariates smoking status, BMI, and Charnley score to the model.

Discussion

In this nationwide registry study, 4 main types of surface modifications on uncemented implants were found to be used in the Netherlands between 2007 and 2021. The most important finding was the variation in revision rates for aseptic loosening between the uncemented implants with different surface modifications.

Table 3
Five- and Ten-Year Major Revision Rates by Kaplan-Meier Analysis Rates of all Total Knee Arthroplasty Groups.

	Total, n	Total Events, n	KM Revision Rate, % (95% CI)	Risk, n
5-year estimate				
Cemented TKA	235,500	4,055	2.2 (2.1 to 2.3)	120,079
Uncemented TKA				
Porous-HA	1,140	11	1.2 (0.5 to 1.9)	553
Porous-uncoated	8,450	193	2.6 (2.2 to 3.0)	5,194
Grit-blasted-uncoated	702	18	2.8 (1.5 to 4.1)	443
Grit-blasted-TiN	179	21	12.7 (7.6 to 17.8)	131
10-year estimate				
Cemented TKA	235,500	4,801	3.1 (3.0 to 3.2)	30,970
Uncemented TKA				
Porous-HA	1,140	15	2.3 (0.9 to 3.7)	118
Porous-uncoated	8,450	206	2.9 (2.5 to 3.3)	1,839
Grit-blasted-uncoated	702	22	4.0 (2.3 to 5.7)	172
Grit-blasted-TiN	179	27	17.4 (11.3 to 23.5)	53

n, number; KM, Kaplan-Meier; TKA, total knee arthroplasty; HA, hydroxyapatite; TiN, titanium nitride.

As the primary objective of uncemented implants is to promote osseointegration at the bone-implant interface, it is noteworthy that significant variations in the rate of aseptic loosening were observed between different groups. These variations ranged from 0.2%-7.9% after 10 years. These results emphasize the significance of identifying the most effective surface modifications to achieve better outcomes. In this study, we found an exceptionally low revision rate for aseptic loosening after 10 years, attributed to the porous-HA (0.2% [95% CI 0.0 to 0.4]) and porous-uncoated (1.3% [95% CI 1.0 to 1.6]) group. It is important to mention that the exceptional results of the porous-HA group may have been influenced by the lower sample size; however, the sample size was larger than most cohort studies and the rate of completeness of the LROI register minimizes the possibility of any missed revisions. Additionally, previous studies support the good performance of implants with a similar surface modification. The recent study by Harwin et al. [23], retrospectively evaluated 805 uncemented porous-HA coated implants and reported a revision rate of 0.1% for aseptic loosening after an average of 4.4 years (range, 2 to 9). Another recent study, which retrospectively examined 1,289 uncemented porous-uncoated Low Contact Stress prostheses, reported a revision rate for aseptic loosening of 1.8% (95% CI 1.0 to 2.6)

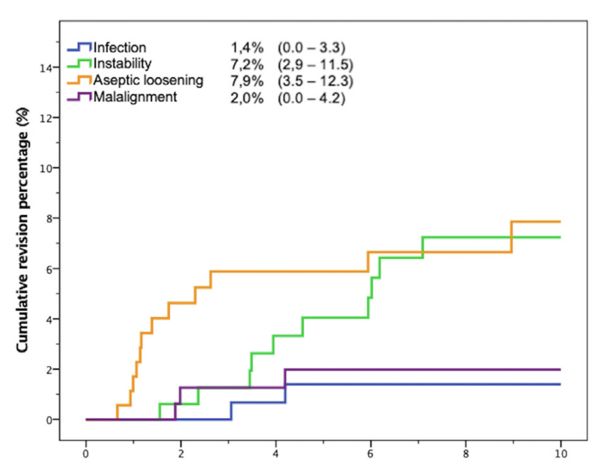

Fig. 4. Cumulative revision rates (95% CI) of different major revision reasons of the grit-blasted-TiN group.

Table 4
Stratified Crude and Multivariable Survival Analyses of Cemented and Uncemented Total Knee Arthroplasties With Different Surface Modification, With Revision for Aseptic Loosening of Any Component as an End point.

	Crude HR (95% CI)	*P* Value	Adjusted HR[a] (95% CI)	*P* Value
Stratum: fixed bearing				
Cemented	REF		REF	
Uncemented				
Porous-HA	0.28 (0.07 to 1.10)	.07	0.28 (0.07 to 1.12)	.07
Porous-uncoated	n/a		n/a	
Grit-blasted-uncoated	2.50 (1.41 to 4.40)	<.01	2.71 (1.46 to 5.05)	<.01
Grit-blasted-TiN	n/a		n/a	
Stratum: mobile bearing				
Cemented	REF		REF	
Uncemented				
Porous-HA	n/a		n/a	
Porous-uncoated	0.75 (0.60 to 0.95)	.02	0.76 (0.60 to 0.98)	.03
Grit-blasted-uncoated	n/a		n/a	
Grit-blasted-TiN	4.27 (2.40 to 7.60)	<.01	4.60 (2.56 to 8.25)	<.01

HR, hazard ratio; REF, reference; HA, hydroxyapatite; TiN, titanium nitride; n/a, not available.
[a] Adjusted for age, gender, ASA classification and previous operations on the affected knee.

after a mean follow-up of 11.1 years (range, 11 to 20) [24]. This population is comparable to the porous-uncoated group in the current study, since the Low Contact Stress implant is also the most commonly used uncemented porous-uncoated prosthesis in the Netherlands, accounting for over 60% of all uncemented prostheses, as reported by the LROI [4]. Similar positive results for porous and HA-coated implants have been observed in studies using RSA. Modern uncemented implants, containing a highly interconnecting porous (trabecular) metal or HA coating, have been found to have lower implant migration and better fixation than other uncemented implants and some cemented implants [18,25,26]. Although trabecular metal implants were not included in the groups of the current study, these studies do indicate what porosity can mean for the results of an implant. In our study, a significantly lower HR for the likelihood of revision for aseptic loosening was found in the porous-uncoated group compared to cemented implants. However, this was not confirmed by the KM analysis, which showed overlapping 95% CI. Based on the results of this study, it can be inferred that implants featuring a porous-uncoated surface modification perform at least as well as cemented implants.

Besides identifying high-performing implants, it is even more important to identify low-performing implants, especially because of patient safety. The disparity between the best and least-performing groups in this study might be attributed to the different underlying purposes of the surface modifications. The HA coating and porous metal aim to promote osseointegration, likely more than grit-blasted metal, while ceramic coatings such as TiN are designed to enhance properties such as hardness, wettability, wear resistance, and friction reduction of an implant [27]. This difference in the use of purpose could be a factor in the observed variation in performance. However, it remains difficult to draw a firm conclusion from these results, since the differences in population characteristics between groups are major. It is recognized that the low sample size (n = 179), the restricted number of hospitals utilizing these prostheses (n = 1), and the limited variety of prostheses with this surface modification (n = 2) likely exerted a significant influence on the results of this group. This is supported by the fact that the major revision rate is also substantially higher than that of other groups, which could indicate that factors other than surface modification, such as prosthesis, surgical, or hospital failure may have contributed to the results. For example, the grit-blasted-TiN implants are the only group that is not used after 2013 (Table 1), which might be a consequence of bad results due to a failing implant design, rather than failing surface modification. However, surgical failure can also be responsible, since outlier-performing hospitals with significantly higher revision rates are not rare [28]. Despite the poor results in this study, TiN coatings are commonly used on uncemented implants, within the literature reported, a substantially lower reported revision rate for aseptic loosening at 10 years (3.9 [29] and 0.9% [30]) than was found in this current study. Although, both these revision rates are from studies that used implants with a porous metal and TiN coating, instead of a Grit-Blasted-TiN coated implant. For that reason, a direct comparison is complicated. Other registry studies could perform similar comparisons, to ascertain the correctness of these results. Until the results of this group can be validated, it is advised to interpret the results with caution, as they may not be representative of all uncemented implants with a grit-blasted surface and TiN coating. To gain a more comprehensive understanding of the effects of surface modifications, future RSA and in vitro studies are necessary to evaluate early migration and surrogates for osseointegration.

This study has several potential limitations to acknowledge. The study was observational and subject to confounding by indication. Only a limited number of variables are collected by the LROI, more detailed information on prosthesis types, brands, applications, and coating thickness could have improved the evaluation of the surface modification effects. Also, not all kinds of surface modifications used in the Netherlands were analyzed. Two other surface modifications (porous-TiN and grit-blasted-polymethylmethacrylate) could not be included, as the proportion of femoral and tibial components with a similar surface modification was below 10%. Incorporating these groups would have heightened the risk of misclassification bias, as it would not have been possible to determine which surface modification was responsible for a certain revision. Furthermore, although the group populations were not the same, making it likely that confounding occurred, this study provides valuable insight into the various surface modifications used and the variations between them. Moreover, the best-performing uncemented groups appeared to be least affected by confounding, indicating that innovation in uncemented implants is ongoing and beneficial.

Conclusion

There were 4 of the 6 main surface modifications in the Netherlands analyzed and revealed varying revision rates for aseptic loosening. Porous metal-HA coated and uncoated uncemented implants had the best revision rates, at least comparable to cemented implants. Grit-blasted uncoated and TiN-coated implants showed underperformance, although other factors ma§y have contributed to these results.

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Appendix

Appendix Table 2b
Five- and Ten-Year Revision Rates by Competing Risk Analysis for Aseptic Loosening of at Least 1 Component of the Total Knee Arthroplasty.

	Total, n	Events			KM Revision Rate, % (95% CI)	Risk, n
		Total TKAs, n	Femoral Components, n	Tibial Components, n		
5-year estimate						
Cemented TKA	235,500	1,373	291	1,269	0.7 (0.7 to 0.8)	120,079
Uncemented TKA						
Porous-HA	1,140	2	0	2	0.2 (0.1 to 0.7)	553
Porous-uncoated	8,450	85	10	82	1.1 (0.9 to 1.4)	5,194
Grit-blasted-uncoated	702	10	1	9	1.6 (0.9 to 3.0)	443
Grit-blasted-TiN	179	10	7	6	5.8 (3.2 to 10.5)	131
10-year estimate						
Cemented TKA	235,500	1,766	405	1,648	1.2 (1.1 to 1.3)	30,970
Uncemented TKA						
Porous-HA	1,140	2	0	2	0.2 (0.1 to 0.7)	118
Porous-uncoated	8,450	93	14	90	1.3 (1.1 to 1.6)	1,839
Grit-blasted-uncoated	702	14	2	12	2.7 (1.6 to 4.5)	172
Grit-blasted-TiN	179	12	8	8	7.3 (4.2 to 12.7)	53

n, number; KM, Kaplan-Meier; TKA, total knee arthroplasty; HA, hydroxyapatite; TiN, titanium nitride.

Appendix Table 3
Five- and Ten-Year Major Revision Rates by Competing Risk Analysis of all Total Knee Arthroplasty Groups.

	Total, n	Total Events, n	KM Revision Rate, % (95% CI)	Risk, n
5-year estimate				
Cemented TKA	235,500	4,055	2.1 (2.0 to 2.2)	120,079
Uncemented TKA				
Porous-HA	1,140	11	1.2 (0.7 to 2.2)	553
Porous-uncoated	8,450	193	2.6 (2.2 to 2.9)	5,194
Grit-blasted-uncoated	702	18	2.8 (1.8 to 4.4)	443
Grit-blasted-TiN	179	21	12.2 (8.2 to 18.2)	131
10-year estimate				
Cemented TKA	235,500	4,801	3.0 (2.9 to 3.1)	30,970
Uncemented TKA				
Porous-HA	1,140	15	2.2 (1.2 to 3.8)	118
Porous-uncoated	8,450	206	2.9 (2.5 to 3.3)	1,839
Grit-blasted-uncoated	702	22	3.8 (2.5 to 5.9)	172
Grit-blasted-TiN	179	27	16.0 (11.3 to 22.7)	53

n, number; KM, Kaplan-Meier; TKA, total knee arthroplasty; HA, hydroxyapatite; TiN, titanium nitride.