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How Does Implant Survivorship Vary with Different Corail Femoral Stem Variants? Results of 51,212 Cases with Up to 30 Years Of Follow-up from the Norwegian Arthroplasty Register

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Abstract

Background The Corail® cementless stem (DePuy Synthes) has been used in Norway since 1987 and is one of the most frequently used stems in THA worldwide. Although the published survival results of the standard Corail stem have been good, little is known about the long-term (more than 20 years) survival of other stem design variants. Further, some changes were made to the extramedullary part of the stem in 2003, and the effect of these changes on survival is unknown.

Questions/purposes (1) What is the survival up to 30 years of the standard collarless Corail femoral stem, and were extramedullary changes (slimmer, polished and rectangular neck, shorter taper) associated with differences in survivorship? (2) How does the 10-year survival and the risk of revision of other Corail stem variants, including the standard collared stem, coxa vara collared stem, and high offset collarless stem, compare with those of the standard collarless stem? (3) Which factors are associated with an increased risk of revision of the Corail stem, and are there any differences in those factors among the four stem variants?

Methods Data for this study were drawn from the Norwegian Arthroplasty Register. Since 1987, THAs have been registered in the Norwegian Arthroplasty Register with completeness of data greater than 97% for primary THAs and 93% for revisions. To study survivorship with up to 30 years of follow-up (1987 to 2018; median 7.7-year follow-up), and to compare the original stem with stems with extramedullary modifications, we included 28,928 standard collarless Corail stems in 24,893 patients (mean age at time of implantation 62 years; 66% [16,525 of 24,893] were women). To compare the newer stem variants with the standard collarless stem (2008 to 2018), we included 20,871 standard collarless, 10,335 standard collared, 6760 coxa vara collared, and 4801 high offset collarless stems. Survival probabilities were estimated using the Kaplan-Meier method with endpoints of stem revision, revision due to aseptic stem loosening, and periprosthetic fracture. The endpoint of all noninfectious causes of THA revision (including cup revision) was

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Ethical approval for this study was obtained from the Norwegian Data Protection Authority (reference number 03/00058-20/CGN).
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additionally analyzed for the long-term comparison. The proportion of patients who died was limited, and there was no difference in death rate between the groups compared. Therefore, we believe that competing events were not likely to influence survivorship estimates to a large degree. To compare different stem variants and evaluate factors that could be associated with the risk of revision, we calculated hazard ratios using Cox regression analyses with adjustments for gender, age group, surgical approach, diagnosis, and stem size.

Results The 30-year Kaplan-Meier survival of the standard collarless stem was 88.4% (95% confidence interval 85.4% to 91.4%), 93.3% (95% CI 91.1% to 95.5%), and 94.4% (95% CI 92.0% to 96.8%) using stem revision for any noninfectious cause, aseptic loosening, and periprosthetic fracture of the femur as endpoints, respectively. There was no difference in survival between the original stem and the modified stem. The 10-year Kaplan-Meier survivorship free of stem revision (all causes including infection) was 97.6% (95% CI 97.2% to 98.0%) for the standard collarless stem, 99.0% (95% CI 98.8% to 99.2%) for the standard collared stem, 97.3% (95% CI 96.3% to 98.3%) for the coxa vara collared stem, and 95.0% (95% CI 93.6% to 96.4%) for the high offset collarless stem. Compared with the standard collarless stem, the standard collared stem performed better (HR 0.4 [95% CI 0.3 to 0.6]; $p < 0.001$) and the high offset collarless stem performed more poorly (HR 1.4 [95% CI 1.1 to 1.7]; $p = 0.006$) with any stem revision as the endpoint, and similar results were found with revision for aseptic stem loosening and periprosthetic fracture as endpoints. Controlling for the noted confounders, the standard collared stem had a lower revision risk. The high offset collarless stem had an increased stem revision risk for any reason (HR 1.4 [95% CI 1.1 to 1.7]; $p = 0.006$) and aseptic loosening (HR 1.6 [95% CI 1.1 to 2.3]; $p = 0.022$). Other factors associated with an increased risk of stem revision for all stem variants were being a man (HR 1.7 [95% CI 1.4 to 2.0]; $p < 0.001$), age 70 to 79 years and 80 years and older compared with the age group of 50 to 59 years (HR 1.6 [95% CI 1.2 to 2.0]; $p < 0.001$ and HR 1.9 [95% CI 1.4 to 2.6]; $p < 0.001$, respectively), the anterior approaches (direct anterior Smith-Petersen and anterolateral Watson-Jones combined) compared with the posterior approach (HR 1.4 [95% CI 1.1 to 1.7]; $p = 0.005$), as well as a preoperative nonosteoarthritis diagnosis (HR 1.3 [95% CI 1.0 to 1.6]; $p = 0.02$) and small stem sizes (sizes 8-11) compared with the medium sizes (sizes 12-15) (HR 1.4 [95% CI 1.1 to 1.6]; $p = 0.001$). The very small sizes (8 and 9) were associated with a 2.0 times higher risk of revision (95%. CI 1.4 to 2.6; $p < 0.01$) compared with all other sizes combined.

Conclusion When using the uncemented Corail stem, surgeons can expect good results with up to 30 years of follow-up. Our results should be generalizable to the typical surgeon at the average hospital in a comparable setting. From our results, using a collared variant would be preferable to a collarless one. Due to an increased risk of periprosthetic fracture, caution with the use of the uncemented Corail stem in patients older than 70 years, especially in women, is warranted. Poorer stem survival should also be expected with the use of small stem sizes. The risk of periprosthetic fractures for the Corail uncemented stem versus cemented stems in different age categories has not been extensively examined, nor has the use of a collar for different age groups and genders, and both should be subjects for further investigation.

Level of Evidence Level III, therapeutic study.

Introduction

During the past decades, the use of uncemented femoral stems in THAs has increased worldwide [6, 35, 41]. The most frequently used uncemented stem in Norway since the inception of the Norwegian Arthroplasty Register in 1987 has been the Corail® (DePuy Synthes), which has been used in more than 50% of all primary THAs annually for the past 10 years [35]. This stem is currently also the most used uncemented stem reported in other countries, including the United Kingdom and Australia [3, 34]. Since it was first introduced in 1986, the standard stem has been supplemented by several stem variants to better accommodate the anatomy of individual patients. Available stem options include two different offsets, two different neck-shaft angles and neck lengths, collared or collarless stems, a stem for patients with dysplasia, a cemented variant, and a longer revision stem.

We previously reported good short-term and medium-term results of the standard collarless stem variant [18, 21], and the inventor group has published results with up to 23 years of follow-up with excellent stem survivorship [42]. The extensive use of this femoral stem over a long period of time now allows us to study the survivorship with up to 30 years of follow-up in our nationwide register, as well as whether changes made to the extramedullary part of the standard stem in 2003 affected survival. Additionally, to our knowledge, the survival of different stem variants has not been investigated.

Therefore, we asked: (1) What is the long-term survival of the standard collarless Corail femoral stem, and were extramedullary changes (slimmer, polished and rectangular neck, shorter taper) associated with differences in survivorship? (2) How does the 10-year survival and the risk of revision of other Corail stem variants, including the standard collared stem, coxa vara collared stem, and high offset collarless stem, compare with those of the standard collarless stem? (3) Which factors are associated with an increased risk of revision of the Corail stem, and are there any differences in those factors among the four stem variants?

Patients and Methods

Study Design and Data Sources

Data for this study were drawn from the Norwegian Arthroplasty Register (NAR). The NAR has registered hip arthroplasties since 1987. The function of the NAR is local and national quality control, and it aims to identify inferior implants and surgical techniques and to monitor trends. Surgeons in all Norwegian hospitals report to the register, and it currently enrolls 97% of all primary THAs and more than 93% of revision THAs [13, 35]. Through personal identification numbers, revisions can be linked to the primary operation, as well as other relevant information such as emigration and date of death. Patients give written consent to the collection of data. The NAR collects surgical data such as operating hospital, date of operation, type of surgery and implant, fixation, laterality, and indication for surgery, as well as patient-related factors such as age, gender, and American Society of Anesthesiologists class. Each implant has a catalog number provided by its manufacturer. The NAR has built an implant library using these numbers and additional details about the individual implants such as type, size, head size, neck length, and offset.

The Corail Stem and its Modifications

The uncemented Corail stems are wedged, straight stems that are fully coated with hydroxyapatite and macrostructured with horizontal and vertical grooves designed to prevent subsidence and rotation. Since it was first introduced in 1986, the stem has been modified. In the newer version that emerged in 2003, known as the Articul/EZE™ Mini Taper stem (DePuy Synthes), the intramedullary part has remained unchanged, but the neck was modified (polished, made slimmer, and rectangular in cross-section) and the taper was shortened. Other than this, the basic stem design remained unchanged throughout the study period. The Corail standard stem system originally consisted of this stem with or without a collar. Since then, it has been supplemented with several different variants to accommodate different anatomic variations (Fig. 1). In Norway, the standard collarless stem has been used since 1987, and the standard collared stem, the coxa vara collared stem, and high offset collarless stem were first used in 2001 and increasingly by 2008 (Fig. 2). Several additional variants have emerged recently (high offset collared, standard 125° collared/collarless, dysplasia stem, short neck collared/collarless), but because these have only been used for a short time and in limited numbers in our country, they were not included in this study.

Study Population

Between 1987 and 2018, 199,882 primary THAs were reported to the NAR. A Corail femoral stem was used in 52,963 of these procedures, representing 74% of cementless stems in the register. We excluded metal-on-metal THAs using the Corail stem because of poor results unrelated to the stem design. We also excluded cemented Corail stems and other newer Corail stem variants because there were few of these implants and a short follow-up time. This resulted in 51,212 Corail stems in 43,318 patients (Fig. 3).

To answer question 1, 28,928 stems (24,893 patients) with the standard collarless stem from 1987 to 2018 were studied. The follow-up for this group ranged from 1 to 30 years, and the median follow-up was 7.7 years. In all, 0.5% (128 of 24,893) of patients emigrated and 20% (4913 of 24,893) of patients died during the study period. The mean age at time of implantation was 62 years (Table 1), and 66% were women (16,525 of 24,893) (value not shown in table).

To compare the four different stem variants (questions 2 and 3), we excluded all stems implanted in 2007 or earlier because not all four stem variants were widely used in Norway before that time. From 2008 on, more than 50 procedures were performed annually for each stem variant. Thus, the final numbers of hips from the period 2008 to 2018 were 20,871 with standard collarless stems, 10,335 with standard collared stems, 6760 with coxa vara collared stems, and 4801 with high offset collarless stems (Fig. 3). The follow-up ranged from 1 to 11 years for all stem variants, and the median follow-up time was 6 years, 4 years, 4 years, and 5 years, respectively. The percentage of patients who died in each group were 10% (2010 of 20,871), 9% (909 of 10,335), 7% (473 of 6760), and 8% (366 of 4801), respectively. The percentage of patients who emigrated was less than 0.5% in each of the four groups. There were some differences in gender, age, diagnosis, surgical approach, and stem size among the four stem variants (Table 2).

Survival of the Standard Collarless Stem and Association with Extramedullary Modifications

To address our first question about the long-term survival of the standard collarless stem, four endpoints were chosen and studied independently: revision of any component of the THA for any noninfectious reason, stem revision for any noninfectious reason, stem revision for aseptic loosening, and stem revision for periprosthetic fracture of the femur.

Fig. 1. The Corail® stem variants (DePuy Synthes) included in this study. From the left, the standard collarless, standard collared, coxa vara collared, and high offset collarless stems. Published with permission from DePuy Synthes.

To examine whether the changes in stem design in 2003 influenced stem survival, we compared the risk of stem revision between the old version and the new one (Articul/EZE Mini Taper) using Cox regression analyses. In addition to the previously mentioned factors, we adjusted for the year of operation. In these analyses, we excluded revision for infection because it has been shown that the revision risk for infection in our register has increased substantially with time [11, 12], and this change could have skewed our results. The stems were followed for 10 years in each group to make the comparison as similar as possible, and the minimum follow-up was 1 year for the individual procedures.

Survival of Four Stem Variants

To address our second research question regarding the comparison of the four stem variants, three endpoints were used: stem revision for any reason (including infection), stem revision for aseptic loosening, and stem revision for periprosthetic femur fracture. Survival probabilities and Cox regression analyses were performed and adjusted for gender, age, diagnosis, surgical approach, and stem size. The standard collarless stem was used as a reference because this stem variant represented 49% (20,871 of 42,767) of the hips included in this part of the study.

Factors Associated with Stem Revision

To address our third research question on factors associated with the risk of stem revision, we performed Cox analyses with the endpoint of stem revision for any reason including infection. To investigate whether there were differences between the stem variants, we performed Cox analyses for each stem variant, adjusted for the confounders of gender, age, diagnosis, surgical approach, and stem size. We performed additional analyses for stem revision for periprosthetic fracture of the femur for both genders. However, for women, we did not adjust for stem size because the large stem was rarely used in women. Also, analyses for the stem sizes 8 and 9 versus all other sizes were performed for the standard collared and collarless variants with endpoint stem revision, one stratified by gender and another stratified by collar or collarless. All analyses were adjusted for the above-mentioned confounders.

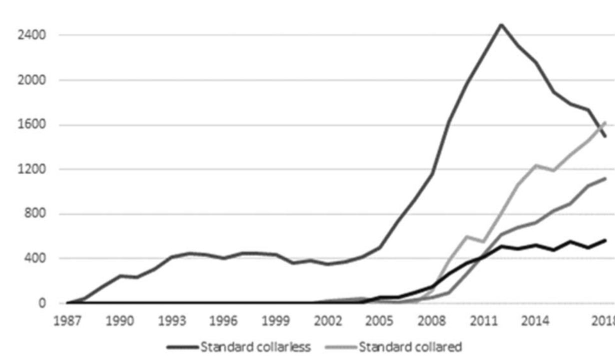

Fig. 2. This graph shows the use of different Corail stem variants reported to the Norwegian Arthroplasty Register between 1987 and 2018.

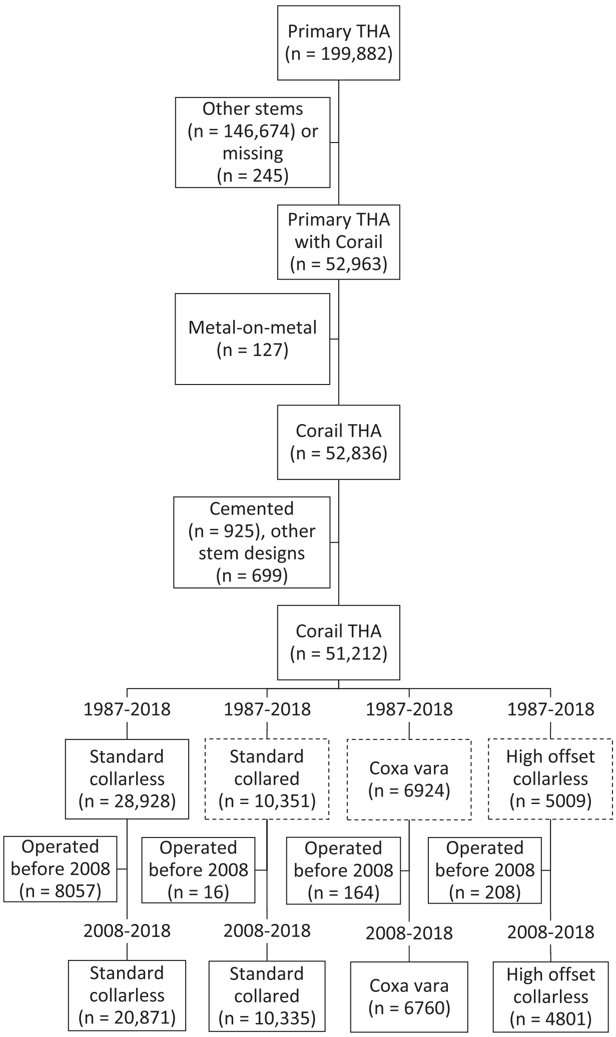

Fig. 3. This flowchart illustrates the inclusion and exclusion process for hips in this study. The cases were reported to the Norwegian Arthroplasty Register between 1987 and 2018.

Table 1. Details of the study population for the Corail standard collarless stem in the Norwegian Arthroplasty Register from 1987 to 2018

Parameter	Total (n = 28,928)
Women	67 (19,388)
Age, years	62.0 ± 12.1
Age group	
< 50	15 (4200)
50-59	25 (7305)
60-69	35 (10,099)
70-79	20 (5757)
80+	5 (1567)
OA diagnosis	71 (20,391)
Surgical approach	
Posterior	39 (11,184)
Anterior[a]	10 (2819)
Lateral	48 (14,014)
Other/missing	3 (911)
Stem size[b]	
Small	41 (11,858)
Medium	56 (16,173)
Large	3 (897)
Version	
Original	20 (5787)
AMT	80 (23,141)

Data presented as % (n) or mean ± SD.
[a]Anterior includes both the direct anterior (Smith-Petersen) and anterolateral (Watson-Jones) approaches.
[b]Small includes stem sizes 8-11, medium includes stem sizes 12-15, and large includes stem sizes 16-20 (arbitrary sizes); AMT = Articul/EZE Mini Taper.

Ethical Approval

Ethical approval for this study was obtained from the Norwegian Data Protection Authority (reference number 03/00058-20/CGN). The registration of data and the study was performed confidentially on patient consent and according to Norwegian and EU data protection rules.

Statistical Analyses

Survival probabilities for the different stem variants were estimated using the Kaplan-Meier method. Results are presented with 95% confidence intervals. The proportion of patients who died was small, and there was no difference in death rates between the groups that were compared. Thus, we think that competing events were not likely to influence survivorship estimate to a large degree. We therefore believe that Kaplan-Meier analysis supplemented with Cox regression analyses were appropriate analyses to study implant survivorship in the present study. We calculated hazard ratios using Cox regression analyses and adjusted them for gender, age group (younger than 50 years, 50-59 years, 60-69 years, 70-79 years, and 80 years and older), diagnosis (osteoarthritis or nonosteoarthritis), surgical approach (anterior, lateral, or posterior), and stem size (arbitrary sizes; small: 8-11, medium: 12-15, and large: 16-20). The surgical approach category "anterior" included both the minimally invasive (MIS) direct anterior (Smith-Petersen, between sartorius and tensor muscles) and MIS anterolateral (Watson-Jones, between gluteus medius and tensor muscles) approaches. In our country, the MIS direct anterior and anterolateral approaches were both introduced between 2009 and 2012, and some hospitals have alternated between the two. Together, they now constitute some 20% of the THAs performed. In previous research, we

Table 2. Details of the study population for each of the four Corail stem variants in the Norwegian Arthroplasty Register from 2008 to 2018

Variable	Total	Standard collarless	Standard collared	Coxa vara collared	High offset collarless
Total number	42,767	20,871	10,335	6760	4801
Women	63 (26,844)	68 (14,271)	71 (7352)	55 (3699)	32 (1522)
Age	65 ± 11	64 ± 11	67 ± 11	67 ± 11	64 ± 11
Age group					
< 50	9 (3773)	10 (2117)	6 (654)	7 (465)	11 (537)
50-59	19 (8187)	21 (4296)	16 (1671)	17 (1122)	23 (1098)
60-69	37 (15,789)	38 (8033)	34 (3511)	36 (2446)	37 (1799)
70-79	27 (11,666)	24 (5076)	32 (3297)	32 (2160)	24 (1133)
80+	8 (3352)	6 (1349)	12 (1202)	8 (567)	5 (234)
OA diagnosis	79 (33,882)	77 (16,082)	80 (8269)	86 (5784)	78 (3747)
Surgical approach					
Posterior	39 (16,546)	44 (9155)	23 (2384)	34 (2306)	56 (2701)
Anterior[a]	25 (10,725)	11 (2212)	46 (4727)	47 (3159)	13 (627)
Lateral	32 (13,732)	41 (8655)	27 (2780)	15 (1022)	27 (1275)
Other/missing	4 (1764)	4 (849)	4 (444)	4 (273)	4 (198)
Stem size[b]					
Small	39 (16,782)	42 (8755)	39 (4074)	38 (2578)	29 (1375)
Medium	58 (24,654)	56 (11,593)	58 (5958)	58 (3941)	66 (3163)
Large	3 (1329)	3 (523)	3 (302)	4 (241)	6 (263)
Missing	0 (1)	0 (0)	0 (1)	0 (0)	0 (0)

Data presented as % (n) or mean ± SD.

[a]Anterior includes both the direct anterior (Smith-Petersen) and anterolateral (Watson-Jones) approaches.

[b]Small includes stem sizes 8-11, medium includes stem sizes 12-15, and large includes stem sizes 16-20 (arbitrary sizes).

found the implant survivorship with the two approaches to be similar, and we chose to group them in this paper [33]. The significance level was set at 0.05, and all tests were two-sided. All statistical analyses were performed using SPSS Statistics, version 26.0.1.0 (IBM Corp), and R version 4.0.2 (R Centre for Statistical Computing).

The inclusion period was 1987 to 2018. The end of the study was December 31, 2019, to secure at least 1 year of follow-up for all patients. Follow-up started on the day of surgery and ended on the day of revision, emigration, death, or on December 31, 2019, whichever came first. The median follow-up time was calculated using the reverse Kaplan-Meier method.

Results

Survival of the Standard Collarless Stem and Association with Extramedullary Modifications

The 30-year Kaplan-Meier survival of the stem, with the endpoint of stem revision for any noninfectious reason, was 88.4% (95% CI 85.4% to 91.4%). It was 93.3% (95% CI 91.1% to 95.5%) for aseptic loosening, and 94.4% (95% CI 92.0% to 96.8%) with the endpoint of stem revision because of periprosthetic femur fracture (Table 3). The 30-year survival of the THA (including cup revision) with the endpoint revision of any component for any noninfectious reason was 50.7% (95% CI 44.9% to 56.5%). The difference in survival between the THA and the stem was evident from an early point after time of implantation (Fig. 4). There were no differences between stem survival of the original stem and the Articul/EZE Mini Taper stem (hazard ratio 1.3 [95% CI 0.9 to 1.9]; p = 0.23) (value not shown in table).

Survival of Four Stem Variants

All stem variants had 95% or higher Kaplan-Meier survivorship with stem revision for any reason as the endpoint (Fig. 5), greater than 97% Kaplan-Meier survivorship with aseptic loosening as the endpoint, and nearly 98% or higher Kaplan-Meier survivorship with periprosthetic fracture of the femur as the endpoint at 10 years (Table 4). The standard collared stem performed better at all three endpoints than the standard collarless stem did, with an adjusted HR of 0.4 (95% CI 0.3 to 0.6; p < 0.001) for the endpoint of

Table 3. Kaplan-Meier survival at 20 and 30 years of the Corail standard collarless stem in the Norwegian Arthroplasty Register with different endpoints from 1987 to 2018

Endpoint	Number of revisions	20-year survival (95% CI) (n at risk 1752)	30-year survival (95% CI) (n at risk 23)
All noninfectious revisions of the THA (cup, liner, and/or stem)	2779	72.8 (71.6-74.0)	50.7 (44.9-56.5)
Stem revision for any noninfectious reason	666	94.7 (94.1-95.3)	88.4 (85.4-91.4)
Stem revision for aseptic loosening	273	97.3 (96.9-97.7)	93.3 (91.1-95.5)
Stem revision for periprosthetic femur fracture	280	97.5 (97.1-97.9)	94.4 (92.0-96.8)

stem revision for any reason. The coxa vara collared variant performed better with periprosthetic femur fracture as the endpoint (HR 0.5 [95% CI 0.3 to 0.8]; p = 0.003) compared with the standard collarless stem. Conversely, the high offset collarless stem had a slightly poorer result for the endpoints of stem revision for any reason (HR 1.4 [95% CI 1.1 to 1.7]; p = 0.006) and aseptic loosening (HR 1.6 [95% CI 1.1 to 2.3]; p = 0.02) (Table 4).

Factors Associated with Stem Revision

In addition to the variant of stem, the following factors were associated with an increased risk of revision of the Corail stem (all four variants combined) for any reason: being a man (HR 1.7 [95% CI 1.4 to 2.0]; p < 0.001), the anterior approaches compared with the posterior approach (HR 1.4 [95% CI 1.1 to 1.7]; p = 0.005), nonosteoarthritis diagnosis (HR 1.3 [95% CI 1.0 to 1.6]; p = 0.02), and small stem sizes compared with medium sizes (HR 1.4 [95% CI 1.1 to 1.6]; p = 0.001) (Table 5). Patients in the age groups of 70 to 79 years and 80 years and older had a higher risk of stem revision than did those aged 50 to 59 years (HR 1.6 [95% CI 1.2 to 2.0]; p < 0.001 and HR 1.9 [95% CI 1.4 to 2.6]; p < 0.001, respectively). Older patients had an increased risk of revision for periprosthetic femur fracture. When compared with the patients aged 50 to 59 years, men older than 70 years had an increased risk of revision with a HR of 2.6 (95% CI 1.4 to 4.9; p = 0.004), and women in the same age group had an even higher risk of revision with a HR of 5.2 (95% CI 2.8 to 9.6; p < 0.001) (values not shown in table). As shown above, the variant of stem was also associated with the risk of stem revision. Age older than 70 years increased the risk of stem revision for the standard collarless and high offset collarless stem variants. The surgical approach was the only factor associated with increased risk of revision for the coxa vara collared and high offset collarless stems. For the coxa vara collared stem, the anterior and lateral approaches increased the stem revision risk, whereas only the anterior approaches increased the revision risk for the high offset collarless stem. Diagnoses other than osteoarthritis increased the revision risk for the standard collared variant, and small stem sizes increased the risk of revision for the coxa vara collared stem (Table 6). When compared with all other stem sizes, the very small sizes (8 and 9) were associated with an increased risk of revision (HR 2.0 [95% CI 1.4 to 2.6]; p < 0.01). When stratified by gender, men with the very small stem sizes had a four times higher risk of revision compared with the larger sizes (HR 4.0 [95% CI 1.9 to 8.3]; p < 0.001). For women, the very small stem sizes had a two times higher revision risk compared with the larger sizes (HR 2.0 [95% CI 1.4 to 2.9]; p < 0.001). There was no difference between

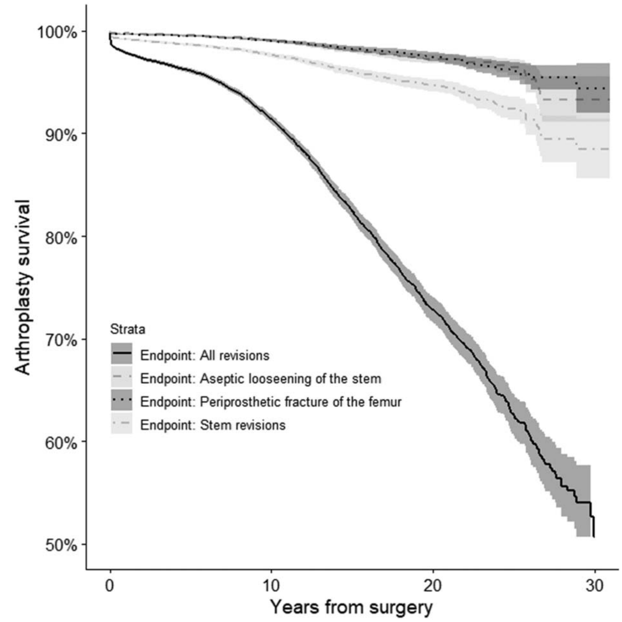

Fig. 4. This Kaplan-Meier curve shows the Corail standard collarless stem from 1987 to 2018 with the endpoints of revision of any component of the THA (including cup revision), stem revision, aseptic loosening of the stem, and periprosthetic fractures of the femur. Revisions for infection were excluded.

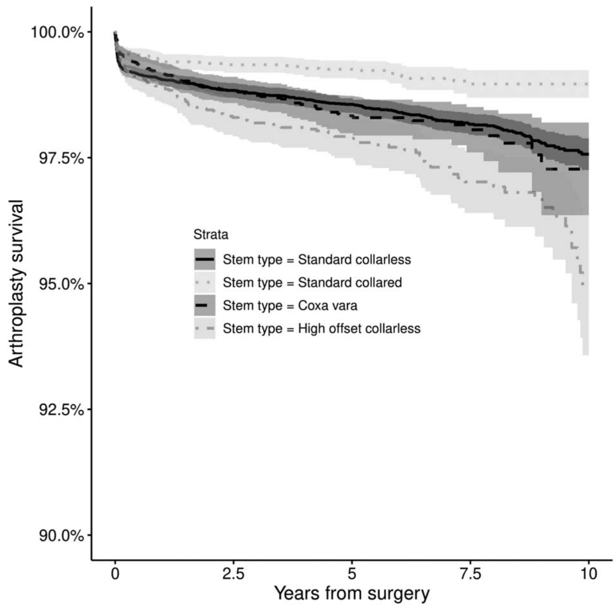

Fig. 5. This Kaplan-Meier curve shows the four Corail stem variants with the endpoint of stem revision for any reason.

the survivorship of standard stems with and without a collar for the very small stem sizes (8 and 9) (HR 1.0 [95% CI 1.4 to 2.6]; p < 0.001) (values not shown in table).

Discussion

Good functional results and predictable survival of up to 10 to 20 years of the Corail stem have been reported [18, 30, 42]. We report results of up to 30 years in a portion of our population with Corail stems, a cementless stem that still is used frequently. During the study period, changes were made to the standard stem and several different stem variants were introduced. Nothing is known about how these design changes and the use of stem variants have influenced overall stem survival. There is also a lack of information on the effect of other factors that could be associated with the risk of stem revision. We found that the 30-year Kaplan-Meier survivorship free of stem revision was 88.4% for the standard collarless stem variant. Changes made to the extramedullary portion of the stem in 2003 did not affect survivorship. The standard collared stem had better survival and the high offset collarless stem had slightly poorer survival after 10 years of follow-up than the standard collarless stem variant did. The standard collared stem was associated with a lower risk of stem revision, aseptic loosening, and periprosthetic fracture than was the standard collarless stem. After adjusting for the confounders of gender, age, diagnosis, surgical approach, and stem size, we found that male gender, age older than 70 years, nonosteoarthritis diagnosis, the anterior approaches, and small stem sizes were factors that were associated with an increased risk of stem revision. Male gender was associated with increased revision risk for all four stem variants, whereas older age was only associated with increased risk for the standard collarless and high offset collarless variants. Based on these results, the use of a collar is preferable, although one should expect poorer results with the uncemented Corail stems in older people and with small stem sizes.

Limitations

There are some limitations to this study. First, because of the long period of data collection, factors other than the implant may have influenced the results, and these factors may have changed with time. For instance, in recent years, we observed an increased risk of revision for infection [10, 12], and thus chose to exclude revisions for the indication of infection in the long-term analysis. Poor survival of uncemented metal-backed cups with conventional nonhighly-crosslinked polyethylene liners influenced the survivorship of the THAs in the present study to a much larger degree than the femoral stems did [15, 16, 19, 20]. This is evident by the poor long-term overall THA survivorship of 72.8% and 50.7% at 20 years and 30 years, respectively, in the present study. Other factors that may also have changed with time include patient-related factors, surgical technique (such as changes in broaching technique) and instrumentation, perioperative treatment, and the threshold for revision. These factors may have influenced, to some degree, the comparison of the original and Articul/EZE Mini Taper versions of the standard collarless stem (question 1). The other analyses should not be affected by time-dependent factors to any great extent. Also, the numbers at risk at 30 years (n = 23) were low. We did have observations with 30 years of follow-up, but most cases had much shorter follow-up. This is reflected by the median follow-up of 7.7 years. Therefore, the 30-year results that are presented have wider confidence intervals reflecting the uncertainty in the estimates. Further limitations to the study include the lack of radiographic and clinical outcomes other than the endpoint of revision surgery and the risk of selection bias, meaning that specific groups of patients are prone to receiving a specific treatment; these limitations are inherent to register studies.

Survival of the Standard Collarless Stem and Association with Extramedullary Modifications

In this study, there was 88.4% survival free from stem revision at 30 years for the standard collarless stem. Several studies have reported good long-term results for the

Table 4. Kaplan-Meier survival at 10 years and Cox regression analyses for the Corail stem variants in the Norwegian Arthroplasty Register from 2008 to 2018

		Stem revision for any reason				Aseptic loosening of the stem				Periprosthetic fracture of the femur			
	Number at risk	Number of revisions, n	Survival (95% CI)	HR (95% CI)	p value[a]	Number of revisions, n	Survival (95% CI)	HR (95% CI)	p value[a]	Number of revisions, n	Survival (95% CI)	HR (95% CI)	p value[a]
Standard collarless	2253	354	97.6 (97.2-98.0)	1(ref)		121	99.1 (98.9-99.3)	1 (ref)		173	98.6 (98.4-98.8)	1 (ref)	
Standard collared	368	80	99.0 (98.8-99.2)	0.4 (0.3-0.6)	< 0.001	18	99.7 (99.5-99.9)	0.3 (0.2-0.5)	< 0.001	34	99.4 (99.0-99.8)	0.4 (0.3-0.6)	< 0.001
Coxa vara collared	126	103	97.3 (96.3-98.3)	0.9 (0.7-1.1)	0.26	43	98.5 (97.7-99.3)	0.9 (0.6-1.4)	0.75	27	98.5 (97.3-99.7)	0.5 (0.3-0.8)	0.003
High offset collarless	336	656	95.0 (93.6-96.4)	1.4 (1.1-1.7)	0.006	42	97.3 (96.1-98.5)	1.6 (1.1-2.3)	0.02	41	97.9 (96.9-98.9)	1.2 (0.8-1.7),	0.39

[a]Cox regression analyses, adjusted for gender, age group, diagnosis, surgical approach, and stem size.

Table 5. Factors associated with risk of revision with endpoint stem revision for any reason in the Norwegian Arthroplasty Register from 2008 to 2018

	Adjusted HR	p value[a]
Gender		
Women (ref)	1	
Men	1.7 (1.4-2.0)	< 0.001
Age group		
< 50	1.2 (0.8-1.6)	0.36
50-59 (ref)	1	
60-69	1.2 (0.9-1.5)	0.14
70-79	1.6 (1.2-2.0)	< 0.001
80+	1.9 (1.4-2.6)	< 0.001
Surgical approach		
Posterior (ref)	1	
Anterior[b]	1.4 (1.1-1.7)	0.005
Lateral	1.0 (0.9-1.2)	0.83
Diagnosis		
OA (ref)	1	
NonOA	1.3 (1.0-1.6)	0.02
Stem size[c]		
Small	1.4 (1.1-1.6)	0.001
Medium (ref)	1	
Large	0.9 (0.6-1.5)	0.78

[a]Cox regression analyses (HR [95% CI]) adjusted for gender, age group, diagnosis, surgical approach, and stem size.
[b]Anterior includes both the direct anterior (Smith-Petersen) and anterolateral (Watson-Jones) approaches.
[c]Small includes stem sizes 8-11, medium includes stem sizes 12-15, and large includes stem sizes 16-20 (arbitrary sizes).

standard collarless Corail femoral stem, with medium-term to long-term survival exceeding 95% [18, 30, 42]. Reports of how the extramedullary changes and introduction of the Articul/EZE Mini Taper stem in 2003 have influenced survivorship are rare. Louboutin et al. [30] reported 95% survival at 12 years for the Articul/EZE Mini Taper stem in 130 patients. We could find no other reports of how the extramedullary changes with the introduction of the Articul/EZE Mini Taper stem have been connected to survivorship. It appears from our findings that these design changes were not associated with a change in stem survival.

Survival of Four Stem Variants

In the present study, all four Corail femoral stem variants had good survivorship, with a Kaplan-Meier survival of 95% or higher at 10 years for the three endpoints studied. The standard collared variant had higher survival at all three endpoints than the standard collarless variant did.

Table 6. Factors associated with risk of revision with endpoint revision for any reason for each stem variant in the Norwegian Arthroplasty Register from 2008 to 2018

	Standard collarless (HR [95% CI])	p value	Standard collared (HR [95% CI])	p value	Coxa vara collared (HR [95% CI])	p value	High offset collarless (HR [95% CI])	p value
Gender								
Women (ref)	1		1		1		1	
Men	1.3 (1.1-1.7)	0.01	1.8 (1.1-3.0)	0.02	2.6 (1.7-3.9)	<0.001	2.0 (1.3-3.3)	0.004
Age group								
< 50	1.3 (0.8-2.0)	0.28	0.6 (0.2-1.8)	0.57	1.0 (0.4-2.2)	0.98	1.6 (0.8-3.3)	0.17
50-59 (ref)	1		1		1		1	
60-69	1.3 (0.9-1.8)	0.11	1.0 (0.5-2.9)	0.96	0.9 (0.5-1.5)	0.61	1.3 (0.8-2.4)	0.32
70-79	1.9 (1.3-2.6),	<0.001	0.9 (0.4-1.9)	0.79	1.0 (0.6-1.8)	0.97	2.2 (1.2-3.9)	0.009
80+	2.5 (1.6-3.9)	<0.001	1.5 (0.7-3.4)	0.33	0.5 (0.2-1.5)	0.22	2.5 (1.1-5.7)	0.04
Surgical approach								
Posterior (ref)	1		1		1		1	
Anterior[a]	1.3 (0.9-1.8)	0.17	1.1 (0.6-2.1)	0.69	1.9 (1.1-3.2)	0.01	1.6 (1.0-2.7)	0.05
Lateral	0.9 (0.7-1.1)	0.39	0.8 (0.4-1.6)	0.57	2.0 (1.1-3.6)	0.03	1.1 (0.7-1-7)	0.69
Diagnosis								
OA (ref)	1		1		1		1	
NonOA	1.3 (1.0-1.7)	0.05	1.9 (1.1-3.2)	0.02	1.1 (0.6-2.0)	0.73	1.0 (0.6-1.7)	0.96
Stem size[b]								
Medium (ref)	1		1		1		1	
Small	1.1 (0.9-1.4)	0.35	1.5 (0.9-2.5)	0.11	2.2 (1.5-3.4)	< 0.001	1.4 (0.9-2.1)	0.11
Large	1.0 (0.5-1.9)	0.95	1.3 (0.4-4.3)	0.65	0.3 (0.0-2.2)	0.24	1.0 (0.5-2.2)	0.96

Cox regression analyses (HR [95% CI], p value), adjusted for gender, age group, diagnosis, surgical approach, and stem size.
[a]Anterior includes both the direct anterior (Smith-Petersen) and anterolateral (Watson-Jones) approaches.
[b]Small includes stem sizes 8-11, medium includes stem sizes 12-15, and large includes stem sizes 16-20 (arbitrary sizes).

After adjustments for gender, age group, diagnosis, surgical approach, and stem size, the risk of stem revision for the standard collared variant was half that of the standard collarless variant. Lamb et al. [29] at the National Joint Registry in the United Kingdom found that the use of a collared uncemented prosthesis was associated with a lower risk of revision for periprosthetic fractures during the first 90 days after surgery. A cadaver study of collared and collarless stems demonstrated that the collar protected against fracture in torsional loading, the mechanism most likely to cause these fractures in vivo [27]. The collared stem variants in the present study had a lower risk of revision for periprosthetic fracture than the standard collarless stem. Our results support the findings from the previous studies and support the use of a collar.

With the numbers available, we were not able to demonstrate an increased risk of stem revision for small stems with high offsets because of the lack of statistical power to show this association. High offset stems have previously been associated with an increased risk of revision in cemented THAs [17, 40, 44]. However, two registry studies from New Zealand and England and Wales examined uncemented stems and offset, and neither found an association between offset and stem survival [25, 44]. The high offset collarless stem was implanted more often in men than in women in the present study. Men frequently have both high offsets and narrow femoral canals, and as a result, may receive smaller stems with high offsets. A high offset leads to an increased load on the stem, which is distributed on a smaller surface area, leading to even more strain on the surface. This may lead to early aseptic loosening [2, 17].

Factors Associated with Stem Revision

We found that being a man, older age, anterior approach, diagnoses other than osteoarthritis, and small stem sizes were associated with an increased risk of stem revision after multiple variable regression analyses. Being a man has previously been shown to be a risk factor for revision THA [4, 5]. Men are generally heavier and taller than females, and the added load might influence the implant performance over time. Younger age is also a factor with negative impact on implant longevity, presumably due to high intensity of use [30, 36, 37, 43]. Older patients are known to have a decreased risk of cemented stem revision [3]. However, this is not applicable to uncemented stems, which may be a less desirable choice for patients older than 70 years. An increased revision rate for periprosthetic fractures has been found for such patients, particularly in women [9, 28, 38, 39], a finding that was confirmed in the present study. In general, the revision risk due to a periprosthetic fracture increased as the patient age increased in the present paper. Some studies have also found that the anterior approaches have an increased risk of revision for aseptic loosening compared with other approaches [7, 24, 26]. Conversely, Charney et al. [7] concluded that the direct anterior approach (Smith-Peterson) had a lower risk of dislocation, revision for instability, and periprosthetic fracture. Mjaaland et al. [33] found no difference among the minimally invasive anterior approaches and posterior and lateral approaches regarding implant survival in the NAR. Other studies have had similar results, with no difference in revision risk between the anterior and posterior approaches [22, 32]. Diagnoses other than osteoarthritis, such as hip dysplasia [14] and rheumatoid arthritis [8], have been found to increase the revision risk, which was noted in our study as well. Smaller femoral stem sizes have a greater revision risk than larger stem sizes [17, 25, 31]. According to the Association for the Research in TRaumatology and Orthopaedics (ARTRO) Group, collared stem variants also face this increased revision risk because of undersizing [1]. Although this was not true for the standard collared stem in our study, the coxa vara collared stem showed a higher risk of revision with small stem sizes. A study from the Australian Orthopaedic Association National Joint Replacement Registry showed that the Corail size 8 and 9 stems had a higher risk of revision compared with the larger sizes, and men with these very small sizes had a higher revision risk than women. These findings compare well with our analyses, though our results show a somewhat lower revision risk. They did not find a difference in the revision risk for collared or collarless stems, and neither did we for the very small sizes (size 8 and 9) in the present paper [23].

Conclusion

When using the uncemented Corail stem, surgeons can expect good results with up to 30 years of follow-up. Our results should be generalizable for the typical surgeon at the average hospital in a comparable setting. Based on our results, using a collared variant would be preferable to a collarless one. Due to an increased risk of periprosthetic fracture, caution with the use of the uncemented Corail stem in patients older than 70 years, especially in women, is warranted. Poorer results should also be expected with the use of small stem sizes. The risk of periprosthetic fractures for the Corail uncemented stem versus cemented stems in different age categories has not been extensively examined, nor has the use of a collar for different age groups and genders, and both should be subjects for further investigation.

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