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ORIGINAL PAPER

Femoral stem subsidence in cementless total hip arthroplasty: a retrospective single-centre study

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Abstract

Purpose and hypothesis Subsidence is a known reason for early failure of total hip arthroplasty (THA). In particular, cementless THA might be vulnerable to migration. The present study analysed femoral stem subsidence after primary cementless THA. Prosthetic and anatomical risk factors for early femoral stem subsidence were evaluated.

Methods Two hundred thirty-one consecutive patients who underwent primary cementless THA in a single centre were retrospectively analysed. Post-operative results were evaluated in consideration of prosthetic and anatomical properties in correlation with subsidence on standing pelvic anteroposterior radiographs. Stem type and design, demographic data, BMI, canal flare index (CFI) and canal fill ratio (CFR) were evaluated.

Results The subsidence rate was significantly higher in collarless femoral stems [3.1 mm (SD 2.8 mm) vs. 1.9 mm (SD 1.5 mm); $p = 0.013$] while the anatomical type of the proximal femur as described by the canal flare index did not influenced subsidence ($p = 0.050$). Also, the canal fill ratio showed no significant correlation with subsidence at any level.

Conclusions In the present study, stem subsidence was significantly higher in the collarless group compared to collared stems. No anatomical parameter (CFI and CFR) could be identified as risk factor for subsidence. Neither age nor BMI influenced subsidence in this cohort. Still, subgroup analysis indicated a sex-dependent role of BMI. Prospective studies of large cohorts should address the problem of subsidence in the future.

Level of evidence Retrospective therapeutic study, Level IV.

Keywords Hip arthroplasty · Stem subsidence · Aseptic loosening · Cementless THA

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Introduction

Subsidence is a known reason for early failure of total hip arthroplasty (THA) [1, 2]. In particular, cementless THA might be vulnerable to migration [1]. Subsidence is defined as a femoral stem distalization in reference to the major trochanter (Fig. 1a, b). The maximum of stem subsidence is observed within the first six to eight weeks post surgery [3–5]. While stem subsidence up to 3 mm is considered to be acceptable, migration above 5 mm is associated with early failure [6]. Still, there is a lack of knowledge regarding reasons for subsidence [1, 4, 7]. Notably, femoral stem type and design as well as anatomical properties might play a relevant role [3, 8]. The use of collared femoral stems is considered preventive for subsidence and probably in this effect superior to collarless stems [9]. Additionally, the canal flare index (CFI) and the canal fill ratio (CFR) are common criteria to describe proximal femoral anatomy and anchorage of femoral stems [3, 8].

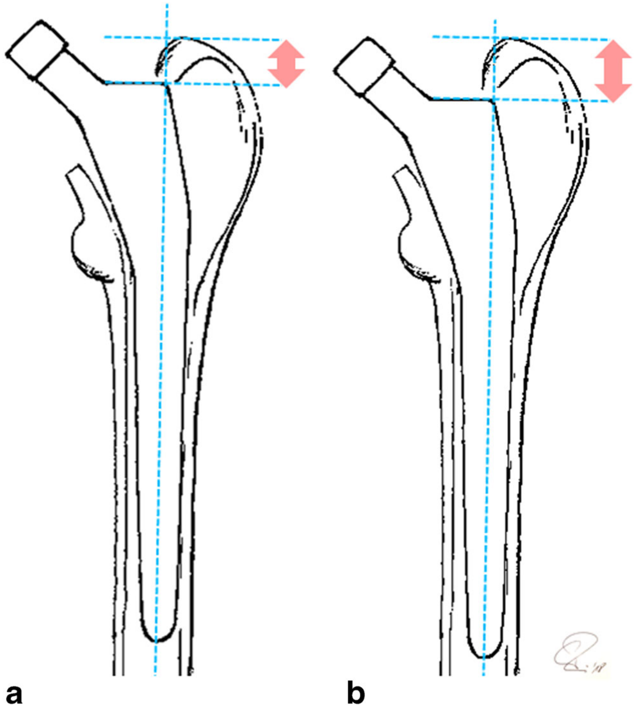

Fig. 1 **a**, **b** Exemplary sketch of femoral stem subsidence measurement. Measurement of the distance between the apex of major trochanter and the stem shoulder perpendicular to the femoral stem axis **a** postoperative and **b** at follow-up. Subsidence is defined as a femoral stem distalization in reference to the major trochanter

The present retrospective study analysed femoral stem subsidence after primary cementless THA. Prosthetic and anatomical risk factors for early femoral stem subsidence were evaluated.

Methods

Patients

In the present retrospective study, 231 consecutive patients who underwent primary cementless THA using a Corail® femoral stem (Fa. DePuy Orthopaedics Inc., Warsaw, IN) between August 2009 and December 2010 in a single centre were included (Fig. 2a, b).

Inclusion criteria were primary THA due to primary or secondary osteoarthritis. Exclusion criteria were malignancy of the femur or the pelvis, severe dysplasia (Hartofilakidis type B or C) or acute trauma. Pre-operative digital templating was performed (Localite OrthoPlanner 2.0, St. Augustin, Germany) using plain anteroposterior radiographs of the pelvis in a standardised standing position. Demographic data of included patients are presented in Table 1.

The study was approved by the local ethics committee (F-2016-112) and followed the most recent version of the Declaration of Helsinki. Due to the retrospective design, no written patient consent was required.

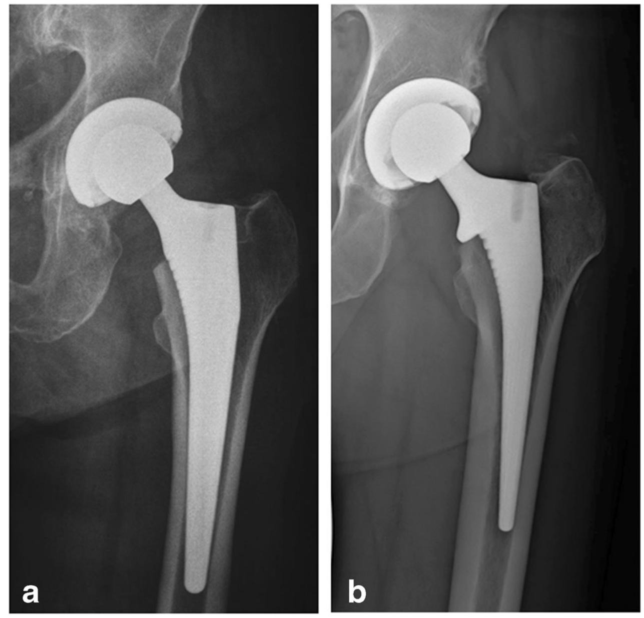

Fig. 2 In the present study, collarless (**a**) and collared (**b**) femoral stems were used for primary uncemented THA

Surgical technique

All THAs were performed by two experienced senior surgeons (CH, WM). The anterolateral or the posterior approach was used following the surgeon's preference. A Pinnacle acetabular component (Fa. DePuy Orthopaedics Inc.) was used in all cases. Decisions regarding femoral stem type were made by the surgeon on an individual basis. For all stems, metaphyseal fixation was aimed for.

Follow-up

A retrospective chart review and radiological analysis was performed for all patients after surgery and at the latest follow-up (minimum 6 weeks). Digital patient charts were reviewed and demographic parameters (age, sex, side, height, weight), implant characteristics, previous operations,

Table 1 Demographic data of 231 cases. Values are given as mean and standard deviations (SD) in brackets. Level of significance < 0.05

	Collarless stems	Collared stems	p value
Sex (M:F)	93:106	8:24	0.021*
Height (m)	1.71 (0.1)	1.67 (0.1)	0.046
Weight (kg)	83.7 (19.0)	79.5 (18.5)	0.119
Body mass index (kg/m^2)	28.6 (5.6)	28.3 (6.3)	0.586
Age (years)	64.4 (9.4)	68.3 (9.8)	0.044
Side (r:l)	93:106	17:15	0.502*

*Chi-square test

Man-Whitney U test

indication for THA, and complications were documented; BMI was calculated.

Radiological analysis

Post-operative results were evaluated on standing pelvic anteroposterior radiographs by independent surgeons. For calibration, the implanted femoral head size was used. All radiographs were examined digitally (Localite OrthoPlanner 2.0) in a random order. The following parameters were collected:

(1) Post-operative radiographs (Figs. 3 and 4a) (within 1 week of surgery): (A) metaphyseal diameter 2 cm above the level of the lesser trochanter midpoint, (B) isthmus diameter, (C) distance between trochanter minor and femoral isthmus, and (D) stem angulation. The width of cortical cortex, intramedullary canal and stem was measured at different heights: (E) at the changeover of proximal and distal stem part, (G) 2 cm proximal of the stem tip and (F) in between measuring points (E) and (G). The distance between the apex of major trochanter and the stem shoulder was measured perpendicular to the femoral stem axis (H).

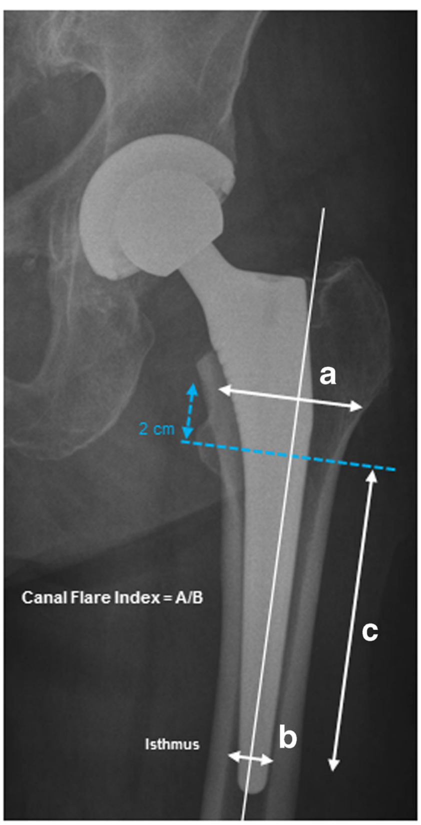

Fig. 3 Determination of canal flare index (CFI): metaphyseal diameter (a) 2 cm above the level of the lesser trochanter midpoint, and isthmus diameter (b). Distance between lesser trochanter and femoral isthmus (c)

(2) Follow-up radiographs (Fig. 4b): stem angulation (I) and the distance between the apex of major trochanter and the stem shoulder (J) was measured analogue to the reference measurement in early post-operative radiographs (H).

Parameter assessment

The CFI was calculated (CFI = A / B). The results were classified as stovepipe (< 3.0), normal (3.0–4.7) and champagne-fluted (> 4.7–6.5) following Noble et al. [8]. Additionally, the CFR was calculated as percentage. Stem subsidence was the difference of parameters (H) and (J). Severity of stem subsidence was grouped in accordance with Al-Najjim et al. [3]: group I < 3 mm, group II 3–5 mm and group III > 5 mm. A deviation from initial stem angulation > 3° was pointed out. Age, sex, BMI, CFI, CFR, stem design, stem size and stem angulation were analysed as possible risk factors for early stem subsidence.

Primary goals of the study were as follows:

- to characterise early stem subsidence after primary cementless THA with a Corail® femoral stem
- to detect prosthetic and anatomical risk factors for early stem subsidence

Statistical analysis

For descriptive analysis, absolute mean values, standard deviations (SD) and ranges of the measured variables are reported. Interquartile ranges and medians are presented for stem sizes. Variables were tested for normality using the Kolmogorov-Smirnov test. For non-Gaussian distributed variables, exploratory analysis was performed using the two-tailed Wilcoxon rank sum test or Man-Whitney *U* test. For bivariate variables, the chi-square test was used. Pearson correlation coefficients (two-sided) were calculated. The level of significance was set at 0.05.

IBM SPSS Statistics 25 for Mac (Statistical Package for the Social Sciences version 25, IBM Corporation, Armonk, NY) and Microsoft Excel for Mac version 15.41 (Microsoft Corporation, Redmond, WA) were used.

Results

One hundred fifty-nine collarless standard stems, 40 collarless high offset stems, 16 collared standard and 16 collared lateralised "coxa vara" stems were implanted. Median implanted femoral stem size was 12 (interquartile range 2) for

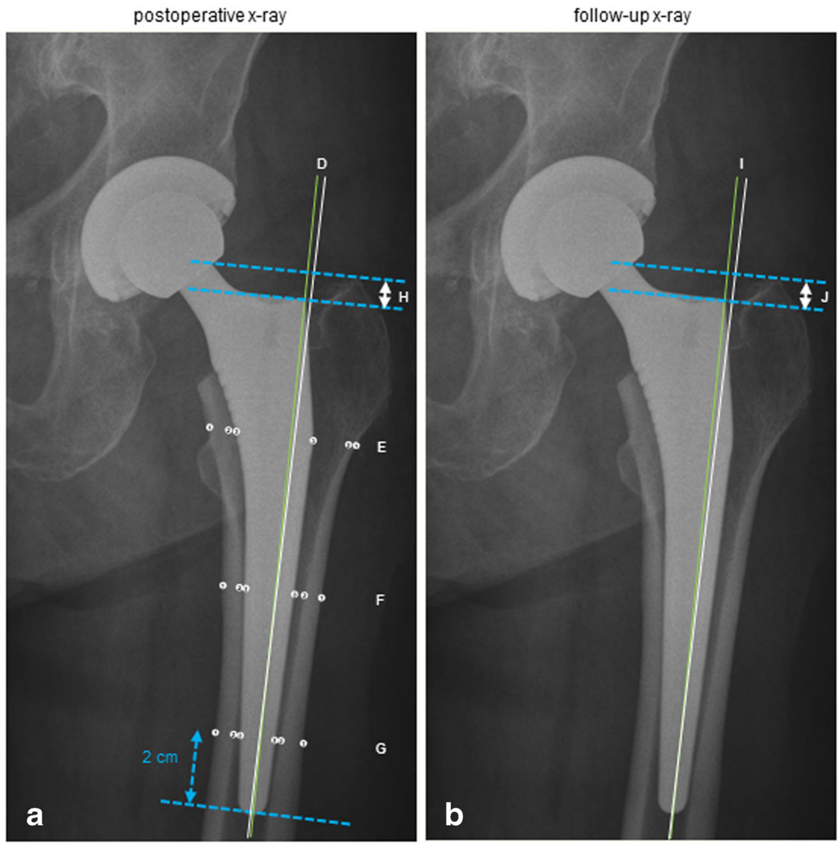

Fig. 4 **a**, **b** Post-operative and follow-up measurements on standing anteroposterior radiographs. The following parameters were measured: stem angulation (D, I), width of cortical cortex, intramedullary canal and stem at different heights: first, at the changeover of proximal and distal stem part (E), second (F) in between measuring point (E) and (G) and third 2 cm proximal of the stem tip (G); distance between the major trochanter apex and the stem shoulder perpendicular to the femoral stem axis (H, J)

collarless stems and 11 (interquartile range 2) for collared stems ($p = 0.006$).

Patients were followed up after a mean of seven (SD 6) months. Three intra-operative complications were observed, none in the collared subgroup. One patient had a major trochanter fissure and two patients had a fissure of the femur, which were addressed with a cerclage wiring (Table 2). No prosthesis was revised during the follow-up period for any reason.

Mean stem subsidence was 2.9 mm (0–20.4 mm; SD 2.7). One hundred forty-three stems showed subsidence below 3 mm (mean 1.4 mm; SD 0.9 mm), 56 between 3 and 5 mm (mean 3.9 mm; SD 0.6 mm) and 32 above 5 mm (mean 7.8 mm; SD 3.4 mm). Mean subsidence was significantly higher in males (3.5 mm; SD 3.2 mm) than in females (2.4 mm; 2.1 mm) ($p = 0.005$).

Univariate analysis of risk factors for stem subsidence identified the femoral stem type (collarless vs. collared) as significant ($p = 0.013$). In contrast, standard and high offset stems did not significantly affect subsidence for both collarless and collared prostheses ($p = 0.390$; $p = 0.090$). Table 3 shows descriptive data of stem type subgroups and a detailed comparison of both.

Descriptive data and comparison of proximal femur anatomy in both subgroups is highlighted in Table 4. Canal flare index type ($p = 0.050$) did not significantly influence subsidence. The Pearson correlation coefficient for subsidence and the CFI was 0.049 ($p = 0.458$). The Pearson correlation coefficient for subsidence and the CFR was − 0.047 ($p = 0.478$) at the changeover of proximal and distal stem parts, − 0.116 ($p = 0.080$) at mid stem and − 0.044 ($p = 0.506$) 2 cm above stem tip. Age, BMI and size of the femoral stem showed no significant correlation with subsidence with coefficients of 0.122

Table 2 Detailed characteristics of patients with an intra-operative complication. *FU*, follow-up

	Sex	Age (years)	BMI (kg/m^2)	CFI	CFR (E) (%)	CFR (F) (%)	CFR (G) (%)	Collared stem	Subsidence (mm)	FU (months)
1	F	75	20.9	3.87	84	73	57	No	12.9	2
2	F	59	25.2	3.56	77	83	64	No	3.1	12
3	F	54	23.9	3.41	79	69	65	No	5.1	27

Table 3 Subgroup analysis of femoral stem subsidence by stem type. Values are given as mean and standard deviations (SD) in brackets. Level of significance < 0.05

	Collarless stems ($n = 199$)	Collared stems ($n = 32$)	p value
Subsidence (mm)	3.1 (2.8)	1.9 (1.5)	0.013
Group I < 3 mm (n)	118	25	0.033*
Group II > 3–< 5 mm (n)	49	7	
Group III > 5 mm (n)	32	0	
Stem angulation >3° (n)	6	8	< 0.001*

*Chi-square test

Man-Whitney U test

($p = 0.065$), 0.001 ($p = 0.988$) and −0.010 ($p = 0.876$), respectively.

Diagnosis of primary or secondary osteoarthritis ($p = 0.154$), previous hip surgery ($p = 0.283$), side ($p = 0.134$) and changes in shaft angulation above 3° ($p = 0.828$) did not significantly influence subsidence.

Discussion

Stem subsidence is considered a relevant factor for early failure of THA. The risk of femoral stem subsidence prior to osseointegration is reported with rates of 5–61.5% in elective hip replacement surgery [6, 10]. However, the roles of stem design and anatomical parameters are not yet completely understood. In this retrospective study, the subsidence rate was significantly higher in collarless femoral stems while the anatomical type of the proximal femur as described by the CFI did not influenced subsidence. Also, correlations of the CFR of the femur and the prosthesis at any level and subsidence were not significant.

Table 4 Subgroup analysis of proximal femur anatomy. Values are given as mean and standard deviations (SD) in brackets. Level of significance < 0.05

	Collarless stems	Collared stems	p value
Canal flare index	3.9 (0.8)	4.0 (0.7)	0.688
"Stovepipe" (n)	23	4	0.843*
"Normal" (n)	146	22	
"Champagne-fluted" (n)	30	6	
Canal fill ratio (%)			
Stem shoulder (E)	67 (10)	63 (10)	0.057
Mid stem (F)	80 (9)	73 (8)	< 0.001
2 cm above stem tip (G)	73 (9)	68 (11)	0.025

*Chi-square test

Man-Whitney U test

Already in 1997, Meding et al. [9] compared collarless and collared femoral stems in 203 consecutive THAs in a randomised trial. Only one case (collarless) showed subsidence over 2 mm and was revised. While no significant differences were found, the authors hypothesised that a collar may prevent migration [9]. In contrast, a large sample of 35,386 cementless THAs (Corail® stem) were retrospectively analysed in the National Joint Registry for England and Wales by Jameson et al. in 2013 [11]. Thirty-one percent were collared stems and the revision rate (hazard ratio) was not significantly different from collarless stems. While 3 of 448 revisions were due to subsidence, the stem design remains unclear in these cases. Additionally, subsidence without revision was not analysed. Consequently, Demey et al. [12] looked deeper into the matter of stem design and migration. They performed a comparative bilateral cadaver study in 20 specimens. Superiority of primary stability to axial and rotational force was found in the collared group. Therefore, Demey et al. routinely use this stem design in primary and revision hip replacements [12]. Comparable to Demey et al., Faisal et al. [13] observed stem subsidence of more than 2 mm in 13 of 206 patients older than 70 years who underwent cementless collarless THA. The authors changed their view due to the study results and henceforth used collared stems assuming that it will be particularly beneficial in the elderly. In particular, poor bone quality may compromise initial press-fit fixation and consecutive bone ingrowth leading to early subsidence, loosening and failure of the implant. Therefore, collared femoral stems might be advantageous in patients with reduced cancellous bone quality. If the collar rests directly on the medial femoral cut, the mechanical stability of the femoral stem is hereby immediately achieved when the patient begins weight-bearing [3] and subsidence of the femoral stem should be avoided. Notably, the contact of collar and bone seems relevant for the primary stability in biomechanical tests [12]. However, in clinical series, only about 39 to 47% of collars have primary contact to the bone [9, 14]. Ishii et al. found up to 61% without primary collarbone contact [15]. Thus, non-contact collars may allow for some migration before a stable bracing is achieved. On the other hand, collared femoral stems have less force transmission distally due to a greater proximal stem loading, which may negatively impact distal femoral stem osseointegration [3, 16].

It is assumed that subsidence usually occurs within the first weeks of weight-bearing [17]. Here, slight subsidence of collarless femoral stems allows loading through the entire surface area of the stem which supports osseointegration and force transmission [3, 16]. Osseointegration usually takes four to 12 weeks but also may take up to three years [18, 19]. The early and slight subsidence of a collarless, cementless femoral stem is potentially an effect of impaction rather than true subsidence due to implant loosening [5]. This hypothesis is supported by Ström et al. [4] who observed early post-operative subsidence of cementless femoral CLS stems followed by stabilisation of the implant. Campbell et al. [1] found in their RSA study a mean subsidence of 0.58 mm (maximum 3.71 mm) at two years for the collarless Corail® stem. The authors observed subsidence to be confined to the first six months following implantation. While Campbell et al. [1] did not follow patients at shorter periods, Selvaratnam et al. [5] as well as Al-Najjim et al. [3] found most of the subsidence occurring within the first six weeks after surgery. A subsidence up to 2 mm is considered within the limits of error for radiographic measurements [2, 20] and a subsidence up to 3 mm seems to be acceptable concerning clinical relevance [6]. In the present study, the mean stem subsidence was 2.9 mm (SD 2.7). Our results are comparable to other studies [1, 3, 13]. However, mean subsidence was significantly higher in males (3.5 mm; SD 3.2 mm) than in females (2.4 mm; 2.1 mm) ($p = 0.005$). This is may be related to the higher body weight in males, which is recognised as a risk factor for implant failure [11]. In the present study, BMI showed significant differences between sexes (27.9 kg/m^2 in females vs. 29.4 kg/m^2 in males; $p = 0.001$) concordant with this assumption.

While the stem design might be relevant, anatomical properties should not be ignored. Biomechanical analysis showed that a close proximal fit of femoral stems optimises the initial torsional stability [21–23], thereby facilitating bony ingrowth [24–26] and minimising fibrous ingrowth [26]. The CFI is a standard means to describe the proximal femoral anatomy and is known to have wide variations. Noble et al. [8] observed a quotient range from 2.4 to 7.0 in 200 investigated specimens, indicating that the femoral medullary canal does not have a universally reproducible shape. In the present study, most patients had a "normal" CFI ($n = 168$) in contrast to "stovepipe" and "champagne-fluted" types. Most recently, Ishii et al. retrospectively investigated the proximal femoral anatomy and the role of the CFR in an Asian population. In particular, a significantly wider CFI (champagne-flute type) was noted in the four failed hips without stem osseointegration ($p = 0.009$) [15]. The authors observed suboptimal radiologic changes with greater distal fill and smaller proximal fill and finally concluded that this could lead to unfavourable long-term clinical outcomes. In our cohort, the subgroup comparison of champagne-fluted ($n = 36$) and non-fluted femora showed a significant difference ($p = 0.015$) with subsidence of 3.6 mm (SD 2.3 mm) and 2.8 mm (SD 2.7 mm), respectively. However, canal flare index type ($p = 0.050$) did not significantly influenced subsidence and Pearson correlation coefficients for subsidence and the CFI showed also no significant results [0.049 ($p = 0.458$)]. Notably, the five cases (Table 5) of subsidence beyond 10 mm were all of the "normal" type. One 75-year-old female had had a subsidence of 12.9 mm after an intra-operative fissure of the major trochanter. All other cases have had no intra-operative complications. However, these patients had a BMI > 25 kg/m^2 combined with a greater distal fill and smaller proximal fill concerning CFR. All cases underwent collarless THA.

We found no correlation of proximal CFR and subsidence. Ishii et al. [15] found the proximal CFR to be 69.1 and 62.8% ($p = 0.02$) for successful and failed proximal osseointegration. However, only collarless stems were observed. In the present study, the proximal CFR at the changeover of proximal and distal stem part was 67% (SD 10%) for collarless and 63% (SD 10%) for collared stem types ($p = 0.057$, Table 4). While Ishii et al. [15] found the distal CFR to be 90–100%, Meding et al. [9] found 95.2% for the collared and 98.7% for the collarless stems. For the tip, no percentages were given. Overall, no clinically differences were found by Meding et al. [9] between stem designs at five years post surgery. We found the CFR between the changeover of proximal and distal stem parts and 2 cm proximal of the stem tip to be 80% (SD 9%) for collarless and 73% (SD 8%) for collared stems ($p < 0.001$). However, it is mentionable that measurement points were not the same in different publications, preventing direct comparison to our results. For example, Ishii et al. [15] analysed the relationships between CFR and femoral morphology using pre-operative and post-operative radiographs. It must be pointed out that this technique proves to be error-prone in terms of a measurement bias due to variations in radiographic projection and magnification [27].

The authors are aware of the limitations of the present study. First, the retrospective study design should be recognised. Additionally, the study groups and the time of follow-up were not homogenous, which potentially influenced our results. The uneven distribution of cases of the

Table 5 Detailed characteristics of patients with a femoral stem subsidence beyond 10 mm. *FU*, follow-up

	Sex	Age (years)	BMI (kg/m^2)	CFI	CFR (*E*) (%)	CFR (*F*) (%)	CFR (*G*) (%)	Collared stem	Intraop. complication	Subsidence (mm)	FU (months)
1	F	75	20.9	3.87	84	73	57	No	Yes	12.9	2
2	M	77	32.2	3.05	64	75	70	No	No	20.4	14
3	M	59	25.9	4.43	68	80	75	No	No	14.5	2
4	F	75	34.8	4.33	72	87	75	No	No	13.5	4
5	M	67	31.8	3.32	65	85	68	No	No	10.0	13

groups with collarless and collared stems is a potential bias that has possibly skewed the final results of this study. The retrospective study design limited the number of cases. Due to possible selection bias, no matched-pair analysis was performed. Rather, the complete cohort of all patients within the study period was included. Thus, selection bias could be prevented. However, all data were presented in detail to provide maximum transparency.

Notably, a minimum follow-up of six weeks was required for inclusion, which is the most relevant time for subsidence to occur. Second, there was no follow-up for clinical outcome parameters. Importantly, no revisions were performed within the follow-up period. Nevertheless, a correlation between femoral stem subsidence and clinical hip function was not assessable. Third, no reliability analysis of the measurements was performed. However, all measurements were performed in accordance with a standardised study protocol. The major strength of this study is the large cohort of a single centre. Highly standardised radiological measurements were performed and multiple risk factors were included into univariate analysis.

Conclusions

In the presents study, stem subsidence was significantly higher in the collarless group compared to collared stems. No anatomical parameter (CFI and CFR) could be identified as risk factor for subsidence. Neither age nor BMI influenced subsidence in this cohort. Still subgroup analysis indicated a sex-dependent role of BMI. Prospective studies of large cohorts should address the problem of subsidence in the future.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

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