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Original article

Bone density and functional results after femoral revision with a cementless press-fit stem

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ABSTRACT

Introduction: The influence of radiographic bone density changes in the area surrounding a total hip arthroplasty (THA) revision with a cementless press-fit stem is unknown, notably in terms of functional results. We have therefore conducted a study aiming to (1) propose a radiographic method to assess bone density, (2) measure the functional effects of reduced bone density, and (3) determine the factors contributing to these modifications.
Hypothesis: A reduction in radiographic bone density has a negative influence on the functional result after revision using a cementless press-fit stem.
Material and methods: We retrospectively assessed 150 THA revisions at a mean follow-up of 6.3 ± 3.2 years (range, 2–15 years). The clinical assessment was based on the Harris Hip Score. Bone density modifications were measured radiographically and the method was evaluated. The change in bone density was classified into two groups: (1) bone density not reduced or < 2 Gruen zones (118 cases [79%]); (2) bone density reduced ≥ 2 zones (32 cases [21%]). The variables showing a potential influence were the Cortical Index (CI), the type of primary stability with the press-fit system, and the femoral implant length.
Results: Inter- and intraobserver reliability of radiographic bone density measurement was evaluated as moderate or good (Kappa, 0.58; 0.60 and 0.67, respectively). For the Harris Hip Score at follow-up, there was a borderline statistical relation between stages 1 and 2: for the 118 stage 1 patients, this score was 83.62 ± 11.54 (range, 27–99) versus 78.34 ± 15.98 (range, 62–91) for stage 2 patients ($P = 0.09$). A CI ≤ 0.44 showed mediocre bone quality contributing to decreased bone density ($P < 0.02$). On the other hand, there was no statistically significant relation with the type of primary fixation ($P = 0.34$) or the length of the implant ($P = 0.23$).
Conclusions: A cementless revision femoral stem can induce a reduction in bone density with possible functional effects. The negative role played by bone scarcity on the functional score is confirmed, and even though the difference is not statistically significant, we suggest using a short stem when this is possible.
Level of evidence: Level IV, historical series.

1. Introduction

The femoral implant can be revised using a first-line cementless femoral stem, a distal interlocking prosthesis in cases with isthmic lesions, a "fit and fill" prosthesis with extended porous coating [1], or a press-fit implant [2] stabilized by creating pressure greater than the destabilizing forces at the bone–implant interface.

All cementless concepts can induce a reduction in bone density qualified as "stress shielding" by Engh et al. [3]. The authors who have evaluated this [1,4,5] underscore the absence of a functional effect of this bone density reduction, maintaining that it is not clinically significant. This can be contested and we believe it is

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pertinent to check whether a reduction in bone density can have an influence on the functional result after femoral revision with a cementless press-fit stem.

The objectives of this study were to:

- propose a radiographic assessment of the changes in bone density and to verify its reliability;
- evaluate whether reduced bone density has a functional effect;
- determine the main factors contributing to a decrease in bone density.

We hypothesized that radiographically assessed bone density reduction has a negative influence on the functional result.

2. Patients and methods

2.1. Patients

This retrospective study investigated a continuous series of 183 total hip arthroplasties performed between 1996 and 2000. Ten patients who had died (6%) were excluded, six patients (3%) were lost to follow-up, and 17 patients (9%) questioned only by telephone were autonomous and without pain. In the end, 150 protheses (82%) in 143 patients (seven bilateral revisions) underwent complete radiological and clinical assessment by an observer who was not involved in the surgeries (MG), at a minimum of 2 years follow-up. There were 74 females and 69 males (59 left hips and 91 right hips). The mean age was 68.9 ± 9.1 years (range, 27–89 years) and the mean follow-up was 6.3 ± 3.2 years (range, 2–15 years).

The causes for revision were: 79 cases of aseptic femoral implant loosening (53%), 47 extensive femoral granulomas (31%), 21 cases of cup loosening with femoral revision to change the bearing components (14%), two periprosthetic fractures, and one case of femoral stem breakage.

According to Della Valle and Paprosky [6], bone loss was stage 1 for 55 cases (37%), stage 2 for 32 cases (22%), stage 3A for 38 cases (26%), stage 3B for 21 cases (14%), and stage 4 for two cases (1%). The two periprosthetic fractures were excluded from this classification.

For 20 patients (13%) this was the second occurrence of loosening and for four patients (3%) the third revision. The explanted femoral stem was cemented in 140 cases (93%) and 19 cups were not changed.

2.2. Surgical technique

All surgeries were performed by a single operator (PLB). The approach to the joint was anterolateral in 26 cases and posterolateral in 124. The original components were removed via the endofemoral approach in 46 cases (31%) and with femorotomy using a lateral semicircular trochanteric-diaphyseal flap in 104 cases (69%), if necessary associated with osteotomy of the medial cortex to extend the primary stability that originally was only diaphyseal. No bone grafting was necessary. The implant was a right cementless femoral stem, conical and modular (Revitan™, Zimmer, Warsaw, IN, USA), in titanium alloy with a finely sanded surface, osseointegratable over its entire length. In the recovery period, partial weightbearing was allowed for 2 weeks.

2.3. Evaluation method

Bone density was radiographically analyzed immediately after the revision surgery and at the last follow-up, with a standard or negative AP X-ray. This comparative analysis consisted in locating demineralized areas characterized by, at the last follow-up, attenuation or disappearance of cortical trabeculations and, for borderline cases, performing a numerical evaluation of the gray level intensity [2]. All the demineralized areas, with or without decreased cortical thickness, were taken into account and classified according to how extensive they were and taking the Gruen zones as reference [7]. Zone 7 was included in zone 6 and cases of cortical necrosis were excluded from the study. Two stages were distinguished: stage 1, bone density not decreased or < 2 zones (Fig. 1) and stage 2, bone density reduction ≥ 2 zones (Figs. 2 and 3).

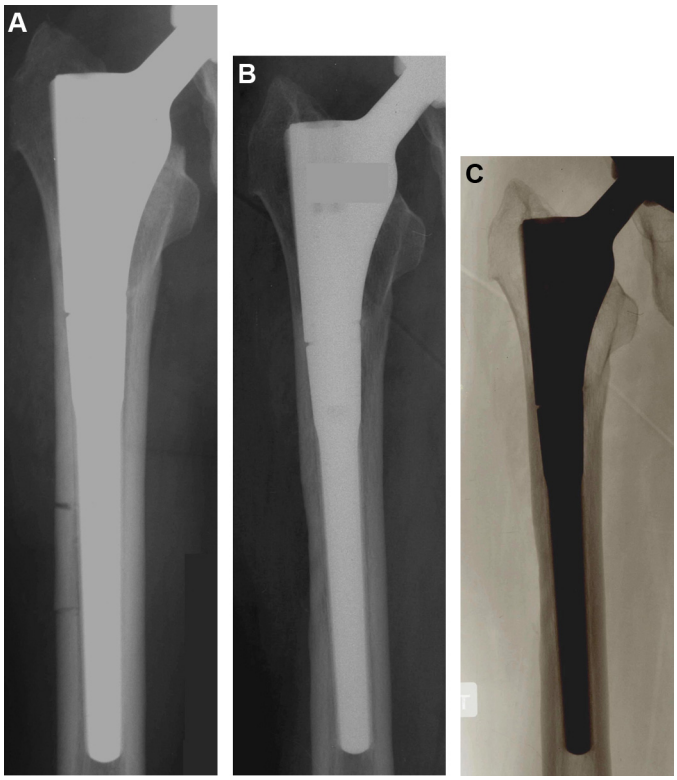

Fig. 1. Stage 1 bone density reduction. A. A 66-year-old female patient, global press-fit stem. B. At the 6-year follow-up, the cortical thickness not modified but proximal femur bone density decrease < 2 zones. C. Bone density reduction more visible on negative X-ray.

The preoperative and follow-up clinical assessment were based on the Harris Hip Score [8] and compared in terms of bone quality as well as the type of primary stability and implant length:

- bone quality was assessed using the Cortical Index (CI), which adds the median and lateral cortical thickness divided by the diameter of the diaphysis. This was a preoperative measurement taken in the isthmic area, outside the loosening area. This index was deemed very good, CI ≥ 0.55, in 30 cases (20%); good, CI between 0.45 and 0.54, in 46 cases (31%); moderate, CI between 0.35 and 0.44, in 56 cases (37%); poor, CI ≤ 0.34, in 18 cases (12%);
- the type of primary press-fit fixation was defined based on the immediate postoperative X-ray by the femur area where there was bicortical bone–implant contact. The primary fixation was proximal in 13 cases (9%), global in 53 cases (35%) (17 via the endofemoral approach and 36 extension with flap), diaphyseal in 46 cases (31%), and with three-point contact in 38 cases (25%);
- three implant lengths were distinguished: short stems (< 200 mm) in 31 cases, long stems between 200 and 250 mm in 60 cases, and extra-long stems (> 250 mm) in 59 cases.

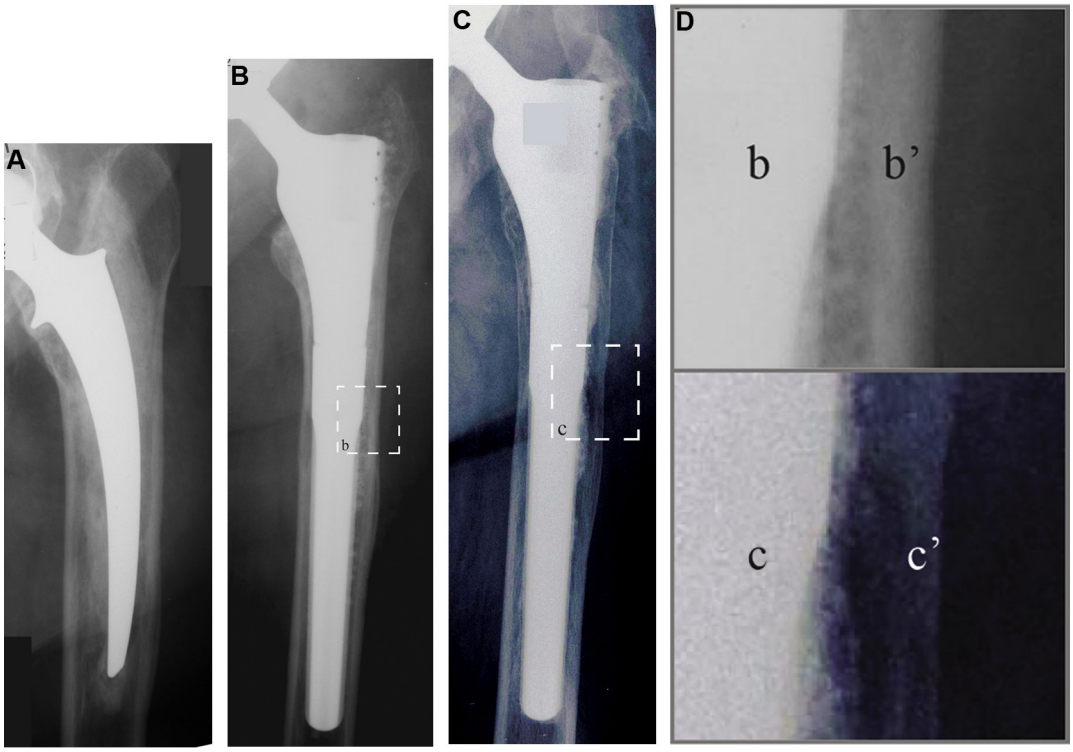

Fig. 2. Stage 2 bone density reduction. A. A 75-year-old female patient, preoperative CI poor at 0.30. B. Press-fit proximal stem. C. At 7-year follow-up, bone density reduction ≥ 2 zones, cortical thickness not modified, CI zone with primary stability at 0.32. D. Measurement of gray intensity in b and c: 50% reduction in bone density in c′.

2.4. Measurements and statistical analyses

All the quantitative radiographic measurements were taken using EvalNet software (LeadTools™; LEAD Technologies, Inc., Charlotte, NC, USA), with the precision confirmed beforehand [9].

The inter- and intraobserver reliability study for the bone density measurement was conducted by two surgeons specialized in hip surgery (TPH, MG) on a sample of 100 X-rays from the group of 150 patients. For the same surgeon, the two evaluations were carried out 10 days apart. It was quantified using the intraclass correlation coefficient (Fleiss type 2), with a 95% confidence interval (CI). An intraclass correlation coefficient < 0.20 was considered poor, mediocre between 0.21 and 0.40, moderate between 0.41 and 0.60, good between 0.61 and 0.80, and very good between 0.81 and 1.00.

The statistical analysis was done using R software (R foundation, http://www.r-project.org/). The quantitative variables are presented with their mean ± standard deviation (range). The difference in pre- and postoperative Harris Hip Scores was tested using the Student *t*-test. The qualitative variables were compared using the chi-square test or the Fisher exact test for small samples. The significance level taken into account was 5%.

3. Results

Interobserver reliability was estimated to be moderate at 0.58, 95% CI (0.41–0.77) and intraobserver reliability to be moderate at 0.60, 95% CI (0.43–0.76) for observer 1 and good at 0.67, 95%CI (0.49–0.85) for observer 2.

Changes in bone density occurred in 118 stage 1 cases (79%) and in 32 stage 2 cases (21%) with 13 patients presenting cortical atrophy. The two groups were comparable for the approaches used (37 cases [31%] the endofemoral approach for stage 1 patients versus ten cases [31%] for stage 2 patients [NS]) and cup change (13 cases [11%] of cups not changed for stage 1 patients versus three cases [9%] for stage 2 patients [NS]). The preoperative Harris Hip Score for the 118 stage 1 patients was 47.23 ± 12.84 (range, 7–95) versus 46.66 ± 14.46 (range, 24–80) for the stage 2 patients ($P = 0.83$). The Harris Hip Score at follow-up for the 118 stage 1 patients was 83.62 ± 11.54 (range, 27–99) versus 78.34 ± 15.98 (range, 62–91) for stage 2 patients, with a trend toward significance ($P = 0.09$) (Table 1).

There was a relation between a decrease in bone density and the CI value ($p < 0.02$): this index was moderate to poor (≤ 0.44) in 27 of the 32 stage 2 patients (84%) versus 47 of the 118 stage 1 patients (40%). No relation was found between the reduction in bone density and the type of primary fixation ($P = 0.34$). It can nonetheless be noted that among the 32 stage 2 patients, 25 (78%) had global or diaphyseal fixation versus seven (22%) patients presenting a proximal primary or three-point fixation. Finally, there was no relation between reduced bone density and implant length ($P = 0.23$). However, it should be noted that among the 25 patients presenting decreased bone density who had received global or diaphyseal fixation, there were 18 (72%) stems longer than 200 mm versus seven stems (28%) shorter than 200 mm (Table 2).

Table 1
Clinical bone density results according to Harris Hip Score [8].

Bone density	Stage 1 ($n = 118$)	Stage 2 ($n = 32$)	*P*-value
Clinical results			
Preoperative scores	47.23	46.66	0.83
Scores at last follow-up	83.62	78.34	0.09
Modifications	+36.39	+31.68	0.17

Stage 1: bone density reduction < 2 Gruen zones; Stage 2: bone density reduction > 2 zones.

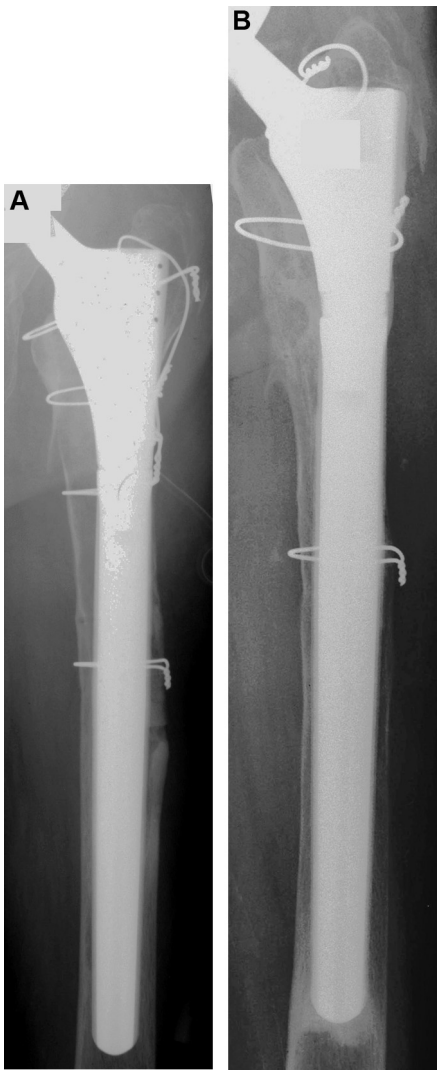

Fig. 3. Stage 2 bone density reduction. A. A 71-year-old female patient, preoperative SI poor at 0.30. Long press-fit diaphyseal stem. B. At 8-year follow-up, bone density reduction ≥ 2 zones, cortical thickness reduced with CI zone primary stability reduced by 0.31 to 0.26.

Table 2
Results of correlation analysis.

Bone density	Stage 1 ($n = 118$)	Stage 2 ($n = 32$)	*P*-value
Cortical Index			< 0.02
Very good to good CI ≥ 0.45 ($n = 76$)	71 (60%)	5 (16%)	
Moderate to poor CI ≤ 0.44 ($n = 74$)	47 (40%)	27 (84%)	
Types of primary stability			0.34
Proximal ($n = 13$)	12 (10%)	1 (3%)	
Global ($n = 53$)	38 (32%)	15 (47%)	
Diaphyseal ($n = 46$)	36 (30%)	10 (31%)	
3-Point ($n = 38$)	32 (27%)	6 (19%)	
Implant length			0.23
Short < 200 mm ($n = 31$)	24 (20%)	7 (22%)	
Long < 200–250 mm ($n = 60$)	51 (44%)	9 (28%)	
Extra-long > 250 mm ($n = 59$)	43 (36%)	16 (50%)	

Stage 1: bone density reduction < 2 Gruen zones; Stage 2: bone density reduction > 2 zones.

4. Discussion

Decreased bone density around a femoral implant is often reported. To measure this, researchers [1,4,5,10,11] use radiographic evaluation and the radiographic classification reported by Engh et al. [3]. This classification is not easy to use however: Gruen zone 7 occupies an important place, although it is often absent during revision or in the case of first-intention reduced height, and reduced bone density located in the distal femur with the proximal femur intact cannot be taken into account. In addition, the distinction does not appear clearly between reduced bone density involving the entire cortical thickness and simple cancellous bone formation of the endosteum [12] located at the bone–implant interface. Finally, it should be emphasized that the term "stress shielding" can also refer to the cortical thickening often located in the distal femur that does not systematically show reduced cortical bone density.

The first limitation of our method is the absence of osteodensitometry measurement, most particularly to screen for bone mineral density loss at its beginnings. To attenuate this disadvantage, we used a numerical evaluation of the gray intensity and a negative X-ray to better visualize the demineralized zones (Fig. 1) and to take into account a reduction in bone density wherever it may be located. Moreover, when osteopenia occurs, it usually comes with thinned cortices with a wide medullary canal and, in these conditions, the CI can also reflect a mediocre bone quality when it is evaluated as moderate or poor. The problem of systematically requiring osteodensitometry in routine practice should also be taken into account, notably for large series. Finally, the present study investigated only one type of implant with no hydroxyapatite (HA) coating and no bone grafting. The impact of these two features on bone density could not be evaluated and the conclusions of Iwana et al. [4], who believe that HA coating could encourage stress shielding, could not be confirmed.

The reliability of our radiographic bone density measurement is satisfactory and the 32 cases (21%) of bone density decrease greater than 2 Gruen zones need to be compared with the results given by Krishnamurthy et al. [5], who observed 29% stress shielding in Engh et al.'s [3] stages 3 and 4. As for the most advanced 13 cases (9%) in the series, corresponding to Engh stage 4, this result should be compared with the 6% observed by Paprosky et al. [1] and 7.6% by Moreland and Bernstein [13].

Those authors [1,5,10], who assessed bone density reduction using the method reported in Engh et al. [3], underscore that stress shielding had no functional effect. This has not been formally confirmed by the present study, which in contrast tends to demonstrate that a decrease in bone density, when extended over more than two Gruen zones, could be a cause of poorer functional results. In addition, the size of the group and its homogeneity (a single implant, a single surgeon) could reinforce this impression, which, however, needs to be confirmed.

Osteopenia that could induce a substantial reduction in bone density of the femoral cortices has often been highlighted [1,5] and, other than the functional repercussions, the problems caused by this should be discussed. On the other hand, the primary fixation mode and the implant length were not discussed in detail and even though the statistical analysis did not show a statistically significant relation between these two factors and bone density reduction, two trends are apparent. One can also cite a possible "preventive" role of primary proximal fixation (a single case in our series), while emphasizing that proximal bone grafting would probably have facilitated this option in several cases of diaphyseal fixation. The higher frequency of primary global or diaphyseal fixation (25 cases) in the 32 stage 2 patients could result from greater disturbed transmission of stresses in flexion with the long stem, leading to excessive stiffening of the bone–implant pair [14] (Fig. 3).

Other than choosing a short stem in these two situations (global or diaphyseal fixation), a stem could be proposed that stabilizes in the frontal plane, which is also the neutral plane in the diaphyseal area [15]. If this option of a short stem is not possible a cementless implant should be discussed, particularly if the CI has been evaluated as poor.

5. Conclusions

Our method for radiographically measuring bone density showed moderate to good reliability. During femoral revision with a cementless press-fit stem implant, the results tend to prove that a reduction in bone density could be the cause of less satisfactory functional results. When planning the surgical strategy, the presence of osteopenia, which facilitates a reduction in bone density, should be considered. Finally, and despite the absence of a statistically significant relation between the reduction in bone density and the type of fixation and stem length, the results of this study tend to prove the unfavorable role played by diaphyseal or global fixation and a long stem.

Disclosure of interest

F.C., O.R., and J.G.: consultants for the firm Zimmer GmbH.

F.B.: financial interests in the firm Amplitude, with no relation to the publication.

P.L.B.: financial interests in the firm Zimmer GmbH.

M.G. declares that he has no conflicts of interest concerning this article.

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