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ORIGINAL ARTICLE • HIP - ARTHROPLASTY

Stem length in primary cementless total hip arthroplasty: Does it make a difference in bone remodeling?

Ahmed M. Samy[1] · **Ahmad El-Tantawy**[1]

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Abstract

Purpose Stem design is usually accused for proximal femoral remodeling following total hip arthroplasty (THA). The aim of this prospective study was to compare the in vivo changes in bone mineral density (BMD) of the proximal femur after implantation of cementless THA with two length alternative stems.

Methods Between May 2011 and March 2014, 50 patients, who met our selection criteria and received cementless THA, randomized into two groups. Group A received cementless standard femoral stems, while group B received short stems. Harris Hip Score (HHS) and visual analog scale (VAS) were used for clinical assessment. Stem and cup positions and stability were radiologically evaluated. Dual-energy X-ray absorptiometry was used to follow and compare changes in BMD in different zones of proximal femur between both groups.

Results After a mean follow-up of 21.4 ± 3.53 months, there was a significant ($p < 0.05$) improvement in mean HHS and VAS with no significant differences ($p > 0.05$) between groups. There was no significant difference ($p > 0.05$) between groups regarding radiological results and rates of complications. The mean overall BMD was decreased by 11.26% for group A and 8.68% for group B at the final follow-up ($p > 0.05$). The greatest loss was found in greater trochanter region for group A and so for group B, but to a lesser extent ($p < 0.05$).

Conclusions Cementless short stem was not able to hold back proximal femoral bone loss, but only can modify or decrease its incidence within limits.

Keywords Hip arthroplasty · Short stem · Bone remodeling · DEXA

Introduction

Bone remodeling is a well-known phenomenon around femoral stems following total hip arthroplasty (THA). This is thought to be a response to mechanical unloading subsequent to changes in the pattern of load transmission around femoral stems (i.e., stress shielding) [1]. Despite being a multifactorial process, stem geometry and designs are suggested among the most important factors affecting proximal femoral remodeling [2]. Marked atrophy of peri-prosthetic bone may predispose to peri-prosthetic fractures, affects implant stability and complicates revision surgery. Therefore, it is crucial to maintain a near-normal load transfer at the proximal femur [3].

In an attempt to decrease stress shielding around femoral stems, short metaphyseal components have evolved with an attractive philosophy based on stability obtained by metaphyseal, not diaphyseal, fitting of the stem. Good bone quality, proper sizing and positioning of the short femoral stem are essential prerequisites to avoid failures. Short-stem designs have, theoretically, the ability for conserving more femoral bone stock and less interfering with the biomechanics of the proximal femur. However, these short-stemmed implants are not fitting for every patient and little is known about their effect on bone remodeling [4].

This prospective clinical study was conducted to compare the in vivo changes in bone mineral density (BMD), as an indicator for bone remodeling, of the proximal femur after implantation of both standard cementless and short-stem cementless femoral components THA, using dual-energy X-ray absorptiometry (DEXA). Our aim was to explore whether there is a major beneficial effect of the more

✉ Ahmed M. Samy
dr.ahmedsamy@yahoo.com

[1] Orthopedic Department, Tanta University Hospital, Tanta University, Tanta, Egypt

demanding and expensive short versions as compared to the more reproducible standard designs.

Materials and methods

This prospective study was conducted between May 2011 and March 2014 in the authors' institution, after approval of the local ethical committee. A total of 50 patients, who met our selection criteria and gave their informed consents for cementless THA, were randomized and divided equally into two groups. Randomization was done by closed envelops of equal number for group A and group B (i.e., 25 envelops for each group) which were opened 2 days before surgery. Group A received cementless standard femoral stems (Spotorno CLS Hip Stem/Zimmer Inc., IN, Warsaw) [5]. Group B received short cementless stems (Mini-Hip, Corin) [6]. These two metaphyseal loading stems were selected to make comparison more precise. The standard stem (CLS stem, group A) is characterized by designs matching the proximal metaphyseal region without attempt to fill the medullary canal distally. For a better proximal load transfer, it has proximal sharpened ribs and three-dimensional wedge shapes proximally for providing intimate primary stability within the metaphyseal region, while the proposed long-lasting mechanical stability could be achieved by osteointegration. The short stem (group B) has an anatomical contour matching the curvature of medial calcar, conserves bone stock and retains femoral neck. It transfers load to the metaphysis progressively in superior to inferior direction with no contact with the diaphyseal region. It is essentially designed to fit more than to fill the metaphysis with primary stability provided by supportive cancellous bone of the metaphyseal region. Its lateral surface and anatomical geometry give good resistance to torsional stress. Additional stability (secondary stability) is usually provided by hydroxyapatite coating [5, 7, 8]. Inclusion criteria included cases with unilateral hip arthritis in patients between 30 and 55 years (Table 1). Exclusion criteria included cases with bilateral involvement, body mass index (BMI) > 35, endocrinal disorders, previous hip surgery, autoimmune disease (e.g., rheumatoid arthritis) and the use of any medication that interfere with bone metabolism (e.g., corticosteroids, alendronate). This is in addition to specific contraindications for short-stem arthroplasty which include significant coxa vara and a short-wide femoral neck.

All cases were operated through direct lateral approach. After iliotibial band incision was performed, the anterior margin of the gluteus medius was cut for about 4–5 cm at its insertion onto the greater trochanter, while the main attachment of the abductors was preserved. Acetabular preparation and implantation of the cementless cup followed the standard procedures of press fitting with or without additional screws (1–3 screws). In all cases, cobalt chrome large heads (32 or 36 mm.) were used in combination with a highly cross-linked polyethylene (XLPE) liner. Femoral components were inserted, on the basis of the results of the preoperative use of templates with the aid of fluoroscopy in all cases to avoid the effect of component malpositioning or size mismatching on the outcomes. Immediate mobilization was encouraged, and standing and partial weight bearing were allowed after removal of the drain using two crutches for 2 weeks after surgery and with one crutch for another 4 weeks. Full weight bearing was allowed after 6 weeks except in the presence of complications. Patients were evaluated immediately after surgery and then followed up regularly at 6 weeks, 3 months, 6 months and 12 months after surgery and yearly thereafter.

Patient evaluation

Clinical evaluation

All patients assessed clinically at the pre- and postoperative follow-up periods according to the Harris Hip Score (*HHS*) [9], and visual analog scale (*VAS*) [10] (Table 2).

Table 1 Patient characteristic in the study

	Group A	Group B	Total
Age: Mean ± SD (range)	48.7 ± 4.93 years (37–55)	45.4 ± 6.81 years (30–52)	47.6 ± 3.51 years (30–55)
Sex: (male: female)	14:11	13:12	27:23
BMI: mean ± SD (range)	27 ± 1.3 (26–35)	28 ± 0.9 (24–33)	28 ± 0.3 (24–35)
Cause of arthritis (indication of surgery)			
1ry O.A. hip	12	15	27
Avascular necrosis	4	8	12
Post-traumatic	6	0	6
D.D.H.	3	2	5
Follow-up: mean ± SD (Range)	20 ± 2.5 (15–31 months)	27 ± 1.2 (17–34 months)	21.4 ± 3.53 months (15–34)

Table 2 Clinical results at the final follow-up as compared to preoperative values

	Group A	Group B	Total
Follow-up (months)			
Mean ± SD (Range)	20 ± 2.5 (15–31)	27 ± 1.2 (17–34)	21.4 ± 3.53 (15–34)
HHS			
Preoperative Mean ± SD	44.10 ± 4.84	47.23 ± 6.68	46 ± 2.9
Final FU Mean ± SD	90.40 ± 5.29	91.41 ± 7.56	90 ± 1.7
VAS			
Preoperative Mean ± SD	76 ± 23	79 ± 18	78 ± 15
Final FU Mean ± SD	38 ± 19	36 ± 9	37 ± 11

Radiological evaluation

Radiology was studied using windows software version 11.2. Antero-posterior and lateral radiographs of the hip and upper femur were done for all cases preoperatively and postoperatively through the above-mentioned follow-up periods. Cup abduction angle (CAA) was used for evaluation of any changes in cup position [11]. Each image was studied by each author separately, and the average value of both readings was recorded. Stem instability was addressed by scoring system developed by Engh et al. [12].

DEXA measurement

All DEXA measures followed the manufacturer's information (Lunar DPX; Lunar, Madison, Wis., USA) with the patient supine, while the affected limb was hold in 15° of internal rotation to avoid variation of BMD values with different degrees of rotation. A scanning mode with a metal removing hip was used in this study, as it has a better resolution than the standard one. After the first scan, the image of each patient was recorded on the system in order to avoid mismatching of the examined area on subsequent measurements [3]. In group A, the proximal femur was divided into seven regions of interest (ROI), according to Gruen et al. [13], to record DEXA values for each zone (Fig. 1a, b). In group B, the matched-size template of the standard CLS stem was superimposed on the postoperative radiographs to determine the seven examined ROI on the femora of this group (Fig. 1c). We used the template of the CLS stem to standardize the investigated ROI in relation to the femora of both groups (i.e., to obtain precise comparison of DEXA records at similar locations of the proximal femur regardless of the difference in stem length between groups). We select this method to investigate DEXA in fixed regions in the femora for overcoming the issue of normal variation in bone density that is usually present between metaphyseal and diaphyseal regions. The first scan was recorded 1 week

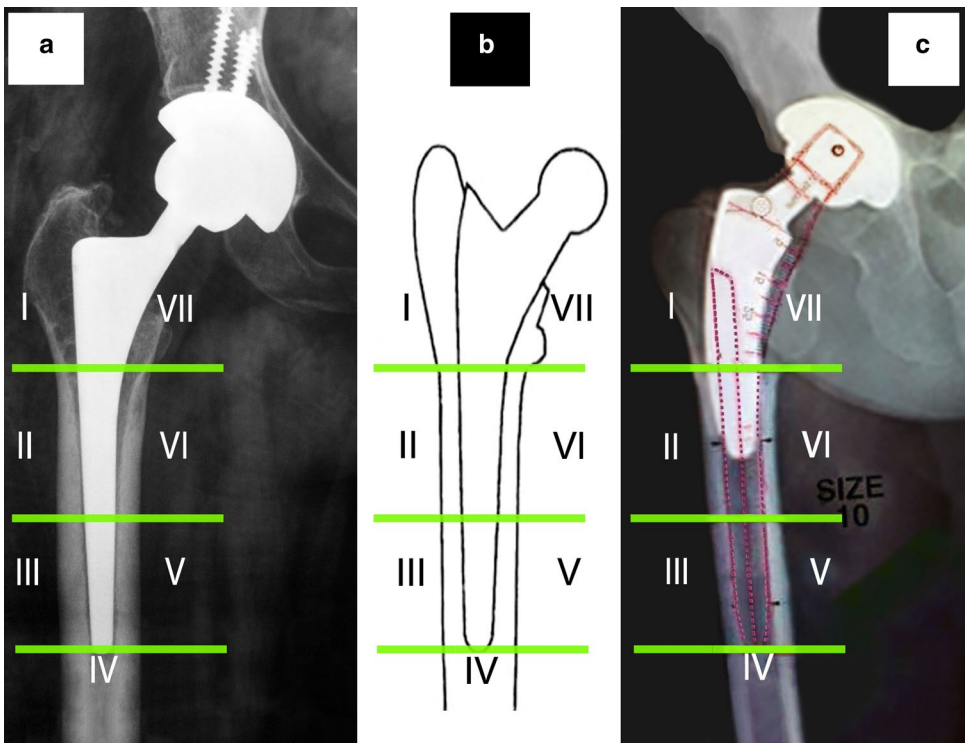

Fig. 1 Illustration of the areas of DEXA measurements: **a** postoperative radiograph of a group A patient with CLS stem showed ROIs, **b** the anatomical landmarks (ROIs) of Greun et al., **c** postoperative radiograph of mini-hip stem of a group B patient with the template of CLS stem (dotted red template diagram) superimposed on the femur in the postoperative radiograph to standardize the ROIs (from I to VII regions) of both groups (color figure online)

postoperatively as a baseline reference value, and then, subsequent follow-up scans were done regularly every 6 months. The mean BMD (g/cm^2) for each of the seven ROI and the overall BMD (net mean BMD) for each group were calculated and measured as a percentage of loss in relation to initial baseline postoperative values rather than absolute normative values (Table 3).

Results

The mean follow-up period was 21.4 ± 3.53 months (range 15–34 months) (Table 1). The results were represented as mean ± SD. Coupled Student's *t* test was used to analyze the differences between baseline and various follow-up values. A *P* value of less than 0.05 was considered statistically significant. Patients of both groups were matched regarding sex, age, BMI, activity, diagnosis and follow-up period (Table 1).

Clinical results

There was statistically significant ($p < 0.05$) improvement in mean HHS and VAS from preoperative to final follow-up evaluation among patients of both groups. However, there were no significant differences ($p > 0.05$) between groups (Table 2).

Radiological results

In both groups, there was no evidence of gross acetabular migration or motion, but some minor changes of CAA were recorded in two patients due to weak or delayed osteo-integration around the cup. Those patients were instructed to continue using two crutches until good osteo-integration was achieved, and we did not record any further changes or loosening thereafter. The CAA was changed from a mean 40.79° and 42.43° at immediate postoperative radiographs to a mean 40.95° and 41.10° at the final follow-up for group A and group B, respectively, with no significant differences between groups ($p > 0.05$). Bone apposition was observed within 6–12 months, with disappearance of the gaps seen in the immediate postoperative radiographs at the bone–implant interface. Significant distal femoral stem migration (> 3 mm) was seen in one patient in group A. This occurred within the first 6 months postoperatively with no further migration thereafter.

DEXA results

The mean overall BMD was decreased by 11.26% for group A and 8.68% for group B at the end of follow-up ($p > 0.05$). The main loss has occurred within the first 6 months in both groups. However, BMD was recovered by 12 months and remained stationary on subsequent measurements till the end of follow-up (Table 3). The greatest loss of BMD was noticed in ROI-1 for group A and so for group B ($p < 0.05$). The least loss in BMD was observed in ROI-5 for both groups. At the end of first year, ROI-5 among group B recorded a little increase in the mean BMD value and this was statistically insignificant ($p > 0.05$). In group A, no further changes were seen in the subsequent measurements except for ROI-7 which showed gradual decrease in BMD until the end of follow-up. Regarding group B, no further changes have occurred in all zones after the first year (Table 3). There was no significant correlation ($p > 0.05$) between changes in BMD and the different studied variables including underlying cause of arthritis, BMI, gender, age, stems size or HHS of both groups.

Postoperative complications

Two cases (4%) of dislocation occurred, and both were in group A. The first one was dislocated within the first month postoperatively due to patient's non-compliance. This patient successfully managed by closed reduction and hip abduction brace with delay weight bearing for 3 weeks. The second

Table 3 Mean percentage ratio of BMD in each zone, at 6 months, 12 months and last follow-up after surgery, as compared to baseline (immediate postoperative) values

ROI	6 months			12 months			Final follow-up		
	Group A	Group B	*P* value	Group A	Group B	*P* value	Group A	Group B	*P* value
ROI-1	65.43 ± 10.40	71.30 ± 15.9	< 0.05	69.10 ± 11.30	82.70 ± 15.09	< 0.05	70.05 ± 13.4	83.20 ± 17.34	< 0.05
ROI-2	84.13 ± 7.98	80.11 ± 9.21	> 0.05	89.04 ± 7.34	84.06 ± 9.03	> 0.05	89.20 ± 9.54	84.80 ± 7.21	> 0.05
ROI-3	91.39 ± 9.32	89.80 ± 7.12	> 0.05	93.90 ± 10.06	92.23 ± 9.56	> 0.05	94.60 ± 11.43	92.1 ± 10.06	> 0.05
ROI-4	90.51 ± 9.76	91.90 ± 5.22	> 0.05	92.80 ± 6.09	94.80 ± 10.34	> 0.05	93.62 ± 7.23	95.01 ± 9.32	> 0.05
ROI-5	93.11 ± 7.23	97.87 ± 12.10	> 0.05	96.99 ± 7.45	100.19 ± 7.86	> 0.05	98.10 ± 6.31	100.04 ± 8.76	> 0.05
ROI-6	83.17 ± 5.20	84.90 ± 9.43	> 0.05	83.80 ± 11.94	87.31 ± 9.76	> 0.05	83.91 ± 10.54	87.21 ± 10.98	> 0.05
ROI-7	78.24 ± 10.39	88.21 ± 14.10	< 0.05	76.67 ± 9.12	90.28 ± 15.06	< 0.05	76.16 ± 14.20	90.23 ± 18.43	< 0.05
Total BMD	82.85 ± 8.61	86.30 ± 10.44	> 0.05	85.33 ± 9.04	90.22 ± 10.96	> 0.05	88.74 ± 10.38	91.32 ± 11.73	> 0.05

one was dislocated twice during first 6 months due to poor soft tissue tension and was revised with longer neck without changing the cup or the stem. Three patients (6%) had developed DVT (one in group A and two in group B) and treated by anticoagulant and rest. Three patients (6%) had developed superficial infection (two in group A and one in group B) and responded well to antibiotic treatment. Apart from the two patients who developed minor changes in CAA and the one who had early femoral subsidence, none of the cases had loosening of any component during the study period.

Discussion

Recently, there is growing interest in understanding changes in peri-prosthetic BMD and the pattern of bone response after implantation of THA [14]. Many authors have reported conflicting results after investigating the different factors affecting peri-prosthetic BMD [3, 15, 16]. However, precise comparison of the results between series is not always possible due to great differences in their stem designs, demographic data and methodology.

In this study, we tried, on a prospective basis, to compare the pattern of bone remodeling, as represented by changes in DEXA, after using two cementless femoral stems that depend mainly on metaphyseal fitting. Group (A) included standard CLS implant, and group (B) included short-stem mini-hip. No significant correlation ($p > 0.05$) was reported between BMD changes, among both groups over the follow-up time, and each of the age, gender and BMI. This can be explained by matching of both groups in their demographic data. Thus, the peri-prosthetic bone remodeling observed in our patients appears to be closely related to implant design rather than patients-related factors. As regards the cause of arthritis and its impact on BMD, many previous studies found no significant effect of this factor on BMD. Conversely, others considered it as a significant risk factor compromising BMD and causing failure after hip resurfacing prosthesis [17]. In this study, we relied on the immediate postoperative DEXA records as a baseline reference. The subsequent follow-up records were calculated as a percentage of this baseline record regardless of the cause of arthritis or the individual variation in DEXA scores. This can explain the negligible effect of this factor in the current research.

Another crucial factor that may affect bone remodeling after THA is the type of surgical approach. Since the muscle and joint reaction forces around the hip joint have a known biomechanical rule on mechanical load transmission, the surgical approach-related trauma and the extent of soft tissue dissection could play a consequential rule in bone remodeling following THA [18]. In the current study, approach was standardized in both groups. So, the effect of this variable on the difference in bone remodeling between the 2 groups, if any, is assumed to be of no substantial value. Furthermore, the used abductor preserving approach can guarantee a near-normal abductor muscle function and joint reaction forces around the hip compared with other relatively more invasive alternatives that involve major splitting and detachment of the abductors. Duda et al. [19] emphasized that splitting and detachment of the abductors from the greater trochanter are predisposing factors promoting bone loss [19].

Although the mean of total bone loss between groups of the current study was statistically insignificant ($p > 0.05$), the loss in group B (8.68%) was less than observed in group A (11.26%). This is in accordance with Rahmy et al. [16] who reported a lesser compromise of BMD after using short-stem designs compared to standard ones [16]. In contrast, some authors reported up to 38% decrease in proximal femoral BMD after insertion of proximal fitted implants either standard or short stems [20, 21]. Implant malpositioning and size miss matching are documented risk factors affecting the way of load transfer through proximal femur and hence affecting BMD and promoting early failures. In this study, there was no single case with malaligned stem that could be attributed to proper patient selection with accurate positioning and sizing of the stems, which was guaranteed by using intraoperative fluoroscopy. Accordingly, we were not able to evaluate the effect of malalignment on the changes on BMD in the present study.

The course of BMD changes of the operated femur across the seven ROI during the follow-up periods showed a similar pattern of bone loss in both groups. However, there was some difference in the percentage of this loss and the areas of highest and lowest loss. In both groups, there was a gradual decrease in the first 6 months that may be attributed to interruption of blood supply during canal preparation and the restricted patient's activity as they underwent transition from partial to full weight bearing. However, recovery of BMD had occurred during the next 6 months and reached a plateau on the later measurements until the end of follow-up. This was harmonized with the findings of Venesmaa et al. [22] and Tran et al. [23], but their plateau was reached within 2–3 years postoperatively [22, 23]. Hayashi et al. [24], in their work about BMD around short stem, found that bone loss occurred up to 12 months postoperatively and recovered at 18 months [24]. We contributed earlier occurrence of the plateau in our study to the better and the more rapid osteointegration between host bone and the implant because of accurate stem sizing and proper technique of press fitting.

Regarding the selective zone variation in BMD changes, Korovessis et al. [25], in their prospective study using the same type of stem as we used in group A, found higher bone mineral loss at the greater and lesser trochanter 4 years after surgery [25]. The greatest loss in the present study was at greater trochanter (ROI-1) which could be attributed to the large cross section of the proximal part of both implants.

These findings are in harmony with previous reports who stated that ROI-1 is more susceptible to bone loss within the first year of operation. Additionally, the bone loss at the greater trochanter (ROI-1) was more pronounced among patients of group A than group B. This could be explained by the different methods of preparation the femora before inserting the stems. The standard (group A) stem requires more bone removal from the metaphysis to provide a well-aligned stem, while the short-stem implantation does not need such removal owing to the curved geometry of its design [26–28].

Previous studies on BMD changes around conventional stems have shown substantial bone loss in calcar zone. The loss reached up to 23% and 20% in the studies of Venesmaa et al. [15] and Rosenthall et al. [29], respectively. This loss was nearly equal to the loss (24%) observed in group A of our study and somewhat better than observed by Pitto et al. [30] who found a 39.6% cortical bone mass decrease in the calcar and trochanteric regions [30]. However, in group B the loss was much lesser than that (< 10% loss). This can be explained by stress shielding in the very proximal portion of the calcar as a result of proximal cross section of the standard implant [4, 29]. However, it has noted that some load bearing seems to take place at the calcar, as the BMD recovered in ROI-7 in group B during the follow-up period. This is in agreement with the cadaveric study of Decking et al. [31] who found reduced strain in the proximal femur after insertion of both the straight and the anatomic stems, and a more physiological strain distribution in the medial region of the hip after short-stemmed implants [31]. Possible unfairness can result from the hydroxyapatite coating, which could affect DEXA measurements, and this may explain the high BMD in ROI-3 and ROI-5 in group B, which represents the transitional zone between hydroxyapatite coated and uncoated distal end of the stem [26]. Tanzer et al. [32] showed that coated stems had significantly less femoral bone loss than the uncoated stems at 2-year follow-up [32]. This has to be taken in consideration when our results compared with other DEXA studies for uncoated stems.

This study confirmed previous findings that neither the short-stem nor the standard-stem designs are immune from proximal bone loss after T.H.A. Additionally, the bone loss observed did not appear to affect the clinical outcomes (HHS and VAS) of our patients, which was also a common finding among previous studies [18, 22–24].

The study has some limitations. First, it is possible that the method of defining ROIs in the present study is criticized because of using the template of the standard (CLS) stem for determining fixed ROIs in relation to the femur among both groups regardless of the stem length. This is somewhat different from the traditional method of identifying Greun zones that depends mainly on determining the ROIs in relation to the stem, regardless of its location in the femur. However, comparing ROIs between two different length stems is a difficult issue. One example of the significant biases when using the traditional method would be the normal variation of BMD between metaphyseal and diaphyseal regions, as the tip of the shorter mini-hip stem is usually located at a higher (metaphyseal) level compared to the longer CLS stem that is usually buried down in the diaphysis. So, we preferred the method used in the present study, as previously described by Hayaishi et al. [24] as our aim was to explore the effect of both stem designs on bone remodeling at fixed ROIs if we imposed their use on the same femur. Second, the short-term follow-up and the relatively small sample size for the DEXA results in some ROI are other shortcomings. The low sample size that was selected for this study was related to the lack of availability of the investigated prosthesis, owing to their expenses, with the restricted number of cases who met our selection criteria. As this study was randomized control one, the selection criteria were sharply restricted to include patients who fit the treatment by any of the studied stem designs. It is well known that there is uncommonness of the patients who fulfill the prerequisites of short-stem designs. For example, cases with significant coxa vara or with short-wide femoral neck, which are known contraindications for short stem, were excluded in this study. Furthermore, many published studies dealing with similar topics included comparable number of patients [33, 34]. Another shortcoming is the absence of preoperative DEXA measurements. Since we had almost matching groups regarding age, gender, type of articulation, patient's activity and BMI, we deemed that the two populations would have comparable preoperative bone mass. We did not perform preoperative DEXA to overcome the expected discrepancy between the pre- and early postoperative records that may result from the effect of medullary preparation by broaching. Additionally, we did not depend on contralateral side as a baseline reference to avoid the variation in bone density that may be present between the affected (i.e., operated) and non-affected sides. The former is usually compromised by long-standing arthritis with the limitation of weight bearing and, hence, the magnitude of applied loads due to pain which may affect the results. This difference was recorded in some studies to be up to 20% [34]. However, future studies with preoperative DEXA measuring in a larger sample of patients and longer follow-up are strongly recommended to confirm our findings.

In conclusion, cementless short stem was not able to holdback proximal femoral bone loss but only can modify or decrease its incidence compared to standard metaphyseal alternatives.

Compliance with ethical standards

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

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