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ORIGINAL ARTICLE

Bone Loss Following Cementless Hemiarthroplasty for the Treatment of Femoral Neck Fracture

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Abstract

Background With the advances in medicine, an increasing number of the ageing population are a public health concern in terms of age-related complications. Among them, displaced neck fractures often require surgical intervention or arthroplasty to achieve the mobilization of the elderly and good life quality. The aim of the study is to monitor the changes in bone mineral density (BMD) around the femoral stem and the effects on functional outcomes in patients treated with cementless hemiarthroplasty following femoral neck fracture.

Materials and Methods Seventy-one patients aged 70 years or older who were treated with cementless hemiarthroplasty for a displaced femoral neck fracture were prospectively followed for 2 years. The percent change in the periprosthetic BMD in each Gruen zone was compared to the baseline using dual-energy X-ray absorptiometry (DEXA). Demographic factors [age, body mass index (BMI), and sex] that could possibly influence BMD and the clinical outcome were evaluated.

Results Fifty-one patients were available for the final follow-up. The mean age was 76.5 (range 70–89) years. The mean BMI was 28.9 (range 22.7–37.2). The mean Harris hip score at the final follow-up was 84.3 (range 72–93). There was a significant decrease in BMD in all Gruen zones ($p < 0.001$), except in zone 3 (R3, $p = 0.547$). The reduction in BMD was highest in the calcar and the greater trochanter region. The femur diaphysis was relatively spared, with zone 3 showing no significant bone mineral loss. The age and BMI of the patients were not correlated with the postoperative change in BMD in any of the Gruen zones. The degree of reduction in bone density was not correlated with the clinical outcome.

Conclusions Cementless hemiarthroplasty for the treatment of femoral neck fracture in elderly patients achieves a good clinical outcome despite significant bone loss around the femoral stem. The reduction in BMD is more pronounced in the metaphyseal region.

Keywords Clinical outcome · Bone loss · Periprosthetic fracture · Elderly · Gruen · DEXA

Introduction

The ageing population is a worldwide concern with socioeconomic and health-related consequences. With increasing life expectancy and decreasing birth rates, the percentage of elderly individuals in the global population is steadily increasing, as is the incidence of health issues associated with old age. Fracture of the femoral neck is a serious but common injury in this patient group and may have devastating consequences despite proper treatment. The burden of this pathology will increase significantly as both life expectancy and the ageing population increase. Projection analysis estimated 6.3 million new cases of femoral neck fracture among elderly individuals with osteoporosis in 2030 [1]. Poor bone quality and the increased number of femoral neck fractures pose a

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significant risk of morbidities in this age group and must be dealt meticulously.

Displaced neck fractures almost always require surgical intervention, such as internal fixation (e.g., using plates, cannulated screws, or intramedullary nails) or arthroplasty. The main purpose of treatment is to achieve a stable hip that permits mobilization as soon as possible to avoid the systemic complications of prolonged immobilization, allow an early return to activities of daily living, and reduce the incidence mortality and morbidities. Arthroplasty stands out as an attractive alternative to internal fixation, because when performed properly, it permits/facilitates early mobilization and full weight bearing, with a lower reoperation rate [2]. While total hip arthroplasty is advantageous in younger patients with higher levels of activity, hemiarthroplasty is still the treatment of choice in elderly patients due to its good long-term results, shorter operation time, lower blood loss, lower dislocation risk, and easier surgical technique [1, 3, 4].

Stable initial fixation of the femoral component inside the medullary canal and the quality of the surrounding bone are the two most important factors of the long-term clinical and radiological outcomes of hemiarthroplasty, including aseptic loosening, pain, stem migration, and periprosthetic fracture [1, 5–8]. This is true for both cementless and cemented designs, and the ideal method of femoral fixation remains a point of debate. Proponents of cemented designs highlight the reduced thigh pain and fracture risk in elderly patients [9, 10], whereas advocates of cementless stems favour them to reduce the operating time [11] and avoid systemic complications of bone cement, although the immediate intraoperative effects of cement have recently been questioned [12]. The cementless arthroplasty procedure is technically less challenging and has a shorter duration and no risk of cement-related complications; these features have led to the increased use of uncemented femoral stems in the treatment of femoral neck fracture [10].

Fracture of the lower extremities induces a loss of bone matrix in the fracture region, which may persist even years after union. This decrease in bone density may not be confined to the trauma site, and general gradual bone loss may occur. Dual-energy X-ray absorptiometry (DEXA) is a valid method for assessing bone density and bone loss around femoral and acetabular components. DEXA is capable of detecting even subtle changes in the bone around a femoral stem [13, 14].

Thus, we designed this prospective study aiming to monitor changes in the periprosthetic bone mineral density (BMD) and the effects of these changes on the functional outcome in patients treated with cementless hemiarthroplasty following femoral neck fracture.

Materials and Methods

This prospective study included patients 70 years or older who were treated with cementless hemiarthroplasty between 2012 and 2014 for a displaced femoral neck fracture. The inclusion criteria were a Garden type 3 or 4 femoral neck fracture and mobility prior to the fracture. Patients with pathological fractures or metabolic bone disease, bedridden patients, patients who could not become mobile after the surgery, and patients with intraoperative fracture that required cable augmentation were excluded.

After approval was obtained from the institutional ethical board, 71 patients (50 F, 21 M) who met the inclusion criteria were prospectively followed for a 2-year period. All patients provided informed consent and were operated on by the same senior surgeon using the posterior approach.

Femoral stems with a proximal hydroxyapatite porous coating and bipolar head were used (F40; Biomet, Inc., Warsaw, IN, USA). Each patient's age, body mass index (BMI), blood transfusion requirements, and hospitalization duration were noted, along with any early or late complications. Patients were allowed full weight bearing with a walker on the first day after surgery under the supervision of a therapist if allowed by their general health status. Early postoperative anteroposterior (AP) and lateral radiographs were obtained to evaluate the stem position. Treatment with low-molecular-weight heparin (LMWH, 6000 IU) was begun on the day of admission and was continued for 3 weeks after the surgery. Demographic factors (e.g., age and BMI) that could possibly influence BMD and the clinical outcome were questioned on the preoperative period and noted.

Periprosthetic bone density in g/cm^2 was measured at the end of the first week using DEXA (Hologic, Explorer (S/N 90621), Hologic, Inc., Bedford, MA, USA) and recorded according to the zones described by Gruen et al. [15]. On the final visit at the end of the second year, the patients were called for a final follow-up consisting of another DEXA scan and an assessment of the functional outcome using the Harris hip score (HHS).

Patients were invited for follow-up visits at 6 weeks, 3 months, 6 months, 1 year, and then every year for clinical and radiological evaluation. AP and lateral radiographs were obtained and compared to the earlier radiographs to identify stem migration or loosening on the postoperative follow-up visits. The stability of the femoral stem, any sign of acetabular protrusion/erosion, and heterotopic ossification were assessed using the radiographs (Fig. 1).

The use of bone strengthening agents such as calcium and bisphosphonates has been introduced in our clinic protocol starting from the year 2016. Since the patients presented here were operated before 2016, we did not prescribe any of these agents to this patient group.

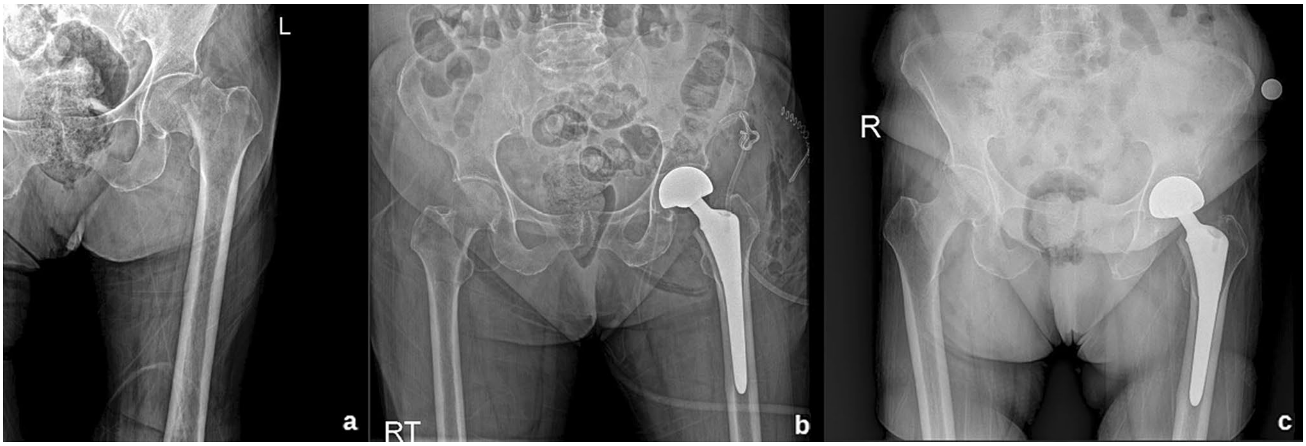

Fig. 1 Radiographs (anteroposterior view) of 78-year-old patient with fracture neck of femur on the left side. **a** Preoperative; **b** immediately after cementless bipolar hemi-replacement; **c** 2 years after cementless bipolar hemi-replacement

The percent change in BMD in each Gruen zone compared to the baseline was assessed for statistical significance using a paired-sample *t* test, since the data were distributed continuously and normally. The correlations between demographic factors and the quantity of bone loss and between the reduction in BMD and the functional outcome were evaluated by multivariate correlation analysis. Statistical tests were performed using SPSS 18.0 software.

Results

Twelve patients died during the postoperative period, and seven were lost to follow-up. One patient developed a periprosthetic infection, and the prosthesis had to be removed. A total of 51 patients (33 females, 18 males) were available for the final assessment at the end of the second year (Fig. 2). The mean age was 76.5 ± 4.2 (range 70–89) years. Twenty-three patients were younger than 75 years, and 28 were older than 75 years. The mean BMI was 28.9 ± 2.9 (range 22.7–37.2). The mean HHS at the final follow-up was 84.3 ± 5.7 (range 72–93). Twenty-eight patients underwent surgery on their left hip, while 23 underwent surgery on their right hip. On the follow-up visits, we did not observe any sign of stem migration, loosening, and pedestal formation on the X-rays of the patients. The X-rays were reviewed in terms of any signs of stem subsidence, and all stems were observed to be centrally positioned.

The initial DEXA results and the change in BMD in the Gruen zones during the 2-year period are outlined in Table 1. There was a significant decrease in BMD in all Gruen zones ($p < 0.001$) at the final follow-up, except in zone 3 (R3, $p = 0.547$). The reduction in BMD was highest in the calcar and the greater trochanter region (Gruen zones 7, 1, and 6, in decreasing order). The femur diaphysis was relatively spared, with zone 3 showing no significant BMD loss (Table 1).

Patients younger than 75 years showed higher BMD in zones 2, 3, and 6 than did patients older than 75 years in the early postoperative period ($p < 0.05$). However, the change in BMD in all Gruen zones throughout the 2-year period was similar in both age groups ($p > 0.05$) (Table 2). The final HHS was also similar in the two age groups. The clinical outcome was similar in patients younger and older than 75 years, who had an HHS of 83.5 ± 5.2 and 84.9 ± 6.1, respectively. There was no significant difference between the two age groups in terms of the clinical outcome (Table 3).

Male and female patients had a similar baseline BMD in all Gruen zones, and the percent change did not differ between males and females ($p > 0.05$) (Table 4). Patient age and BMI were not correlated with the postoperative change in BMD in any of the Gruen zones, except for a weak inverse relationship between BMI and BMD in zone 3 (r: −0.327, $p = 0.019$). The degree of reduction in BMD was not correlated with the clinical outcome in terms of the HHS at the final follow-up (Table 4).

The mean perioperative bleeding was 180 ml (range 100–350 mL) and mean blood transfusion was 0.6 units (range 0–2 units). The mean duration of hospital stay was 9.8 days (6–12 days). No minor complications were observed in the early and late postoperative period.

Discussion

The treatment of hip fractures in elderly patients remains problematic. The ambulatory ability of patients in this group with significant comorbidities is further complicated by prolonged immobilization and reduced ambulation. Both the fracture itself and the subsequent reduced load bearing

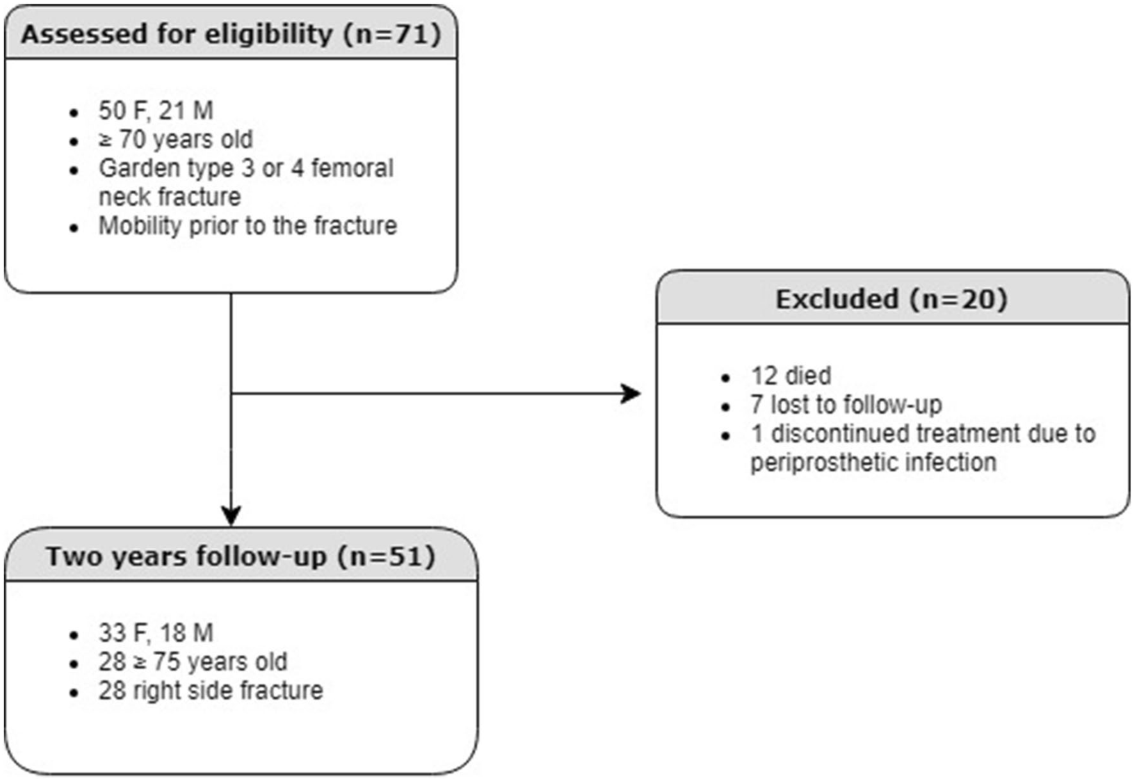

Fig. 2 Flowchart of patients who met inclusion/exclusion criteria for the study population

Table 1 Change in BMD in seven Gruen zones

	Postoperative 1 week	Postoperative 2 years	Percent change	*p*
G1	0.67 ± 0.18	0.55 ± 0.15	− 18 ± 5	**< 0.001**
G2	1.12 ± 0.25	1.02 ± 0.24	− 8 ± 9	**< 0.001**
G3	1.35 ± 0.26	1.37 ± 0.24	18 ± 127	0.547
G4	1.48 ± 0.24	1.36 ± 0.20	− 7 ± 14	**< 0.001**
G5	1.41 ± 0.23	1.33 ± 0.23	− 5 ± 8	**< 0.001**
G6	1.01 ± 0.29	0.85 ± 0.23	− 15 ± 14	**< 0.001**
G7	0.78 ± 0.20	0.62 ± 0.15	− 20 ± 5	**< 0.001**

Significant values were determined as bold

G Gruen zone, *BMD* bone mineral density

are thought to contribute to the occurrence of rapid bone loss, which may persist even after 5–10 years despite proper treatment [16]. Several studies have noted more generalized BMD loss following fractures, which may indicate a systemic reaction rather than an isolated cellular response to reduced mechanical loading at the fracture site [17]. In our study, patients were permitted full weight bearing starting on the first day after surgery. Nevertheless, it was not realistic to expect the patients to return to their preoperative ambulatory status during the recovery period. The total time the patients spent on their feet was most likely reduced, leading to reduced mechanical stimulation of the bones of the lower extremities.

Boe et al. proposed that mineral loss around an implant could be comparable to the bone resorption phase of the remodelling process, yet the exact aetiology remains unclear [18]. Several factors have been shown to affect the degree and extent of periprosthetic bone loss following the surgery. The geometry and load distribution of cementless components is one such factor that is thought to influence areas of bone resorption around the femoral stem. Hayashi et al. reported the relative preservation of bone in the proximal femur using triple-tapered stems, which improved the loading of the neck and metaphysis [13]. They noted as little as 3% BMD loss in Gruen zone 1, whereas straight tapered designs resulted in up to 29% bone loss after 24 months.

Table 2 Baseline BMD and percent change in the two age groups

Age	< 75 years Mean BMD (range)	≥ 75 years Mean BMD (range)	
G1			
Postoperative 1 week	0.66 (0.37 to 1.08)	0.63 (0.37 to 1.08)	0.486
Percent change at 2 years	−17 (−0.4 to −0.1)	−18 (−23 to −8)	0.612
G2			
Postoperative 1 week	1.21 (0.67 to 1.48)	1.12 (0.43 to 1.48)	**0.032**
Percent change at 2 years	−12 (−16 to 6)	−8 (−22 to 26)	0.051
G3			
Postoperative 1 week	1.39 (1.23 to 1.75)	1.36 (0.11 to 1.75)	**0.030**
Percent change at 2 years	−6 (−13 to 29)	−1 (−37 to 901)	0.368
G4			
Postoperative 1 week	1.5 (1.02 to 2.01)	1.46 (0.97 to 2.01)	0.395
Percent change at 2 years	−9 (−41 to 45)	−7 (−20 to 12)	0.319
G5			
Postoperative 1 week	1.45 (1.03 to 1.83)	1.38 (1.03 to 1.75)	0.470
Percent change at 2 years	−4 (−12 to 16)	−6 (−46 to 7)	0.324
G6			
Postoperative 1 week	1.09 (0.47 to 1.61)	0.91 (0.45 to 1.46)	**0.009**
Percent change at 2 years	−18 (−22 to 5)	−18 (−35 to 77)	0.645
G7			
Postoperative 1 week	0.87 (0.4 to 1.18)	0.69 (0.42 to 1.15)	0.084
Percent change at 2 years	−22 (−34 to −9)	−20 (−29 to −4)	0.142

Significant values were determined as bold

G Gruen zone, *BMD* bone mineral density, *SD* standard deviation

Table 3 Baseline BMD and percent change for both sexes

Sex	Male Mean BMD (range)	Female Mean BMD (range)	
G1			
Postoperative 1 week	0.63 (0.53 to 0.99)	0.63 (0.37 to 1.08)	0.876
Percent change at 2 years	−17 (−40 to −11)	−17 (−23 to − 8)	0.230
G2			
Postoperative 1 week	1.14 (0.43 to 1.48)	1.19 (0.6 to 1.48)	0.339
Percent change at 2 years	−13 (−22 to 26)	−10 (−22 to 15)	0.952
G3			
Postoperative 1 week	1.37 (1.17 to 1.75)	1.38 (0.11 to 1.75)	0.094
Percent change at 2 years	−2 (−11 to 29)	−3 (−37 to 901)	0.485
G4			
Postoperative 1 week	1.57 (1.07 to 2.01)	1.49 (0.97 to 1.86)	0.076
Percent change at 2 years	−9 (−41 to 12)	−6 (−33 to 45)	0.222
G5			
Postoperative 1 week	1.47 (1.13 to 1.83)	1.37 (1.03 to 1.83)	0.227
Percent change at 2 years	−7 (−17 to −1)	−4 (−46 to 16)	0.174
G6			
Postoperative 1 week	1.02 (0.45 to 1.56)	0.97 (0.64 to 1.61)	0.629
Percent change at 2 years	−18 (−35 to −6)	−17 (−26 to 77)	0.345
G7			
Postoperative 1 week	0.85 (0.53 to 1.15)	0.78 (0.4 to 1.18)	0.272
Percent change at 2 years	−21 (−25 to −5)	−20 (−34 to −4)	0.752

G Gruen zone, *BMD* bone mineral density, *SD* standard deviation

Table 4 Correlations of change in BMD with demographic factors and clinical outcome

Correlation	Age		BMI		HHS	
	r	*p*	*r*	*p*	*r*	*p*
G1	0.050	0.728	0.228	0.107	0.021	0.881
G2	0.207	0.145	**−0.327**	**0.019**	0.068	0.637
G3	−0.021	0.885	−0.108	0.450	−0.004	0.978
G4	−0.033	0.816	0.131	0.359	−0.139	0.332
G5	−0.172	0.229	−0.050	0.728	0.270	0.056
G6	0.094	0.512	0.044	0.758	0.096	0.503
G7	0.212	0.136	−0.163	0.253	−0.056	0.695

Significant values were determined as bold

G Gruen zone, *BMD* bone mineral density, *r* correlation coefficiency between continuous variables and change in bone mineral density, *BMI* body mass index, *HHS* Harris hip score

In our study, the BMD loss ranged from 8 to 20% in the proximal region after 2 years. Although a direct comparison may be misleading due to differences in component designs and patient samples (i.e., we used Biomet components and included only fracture patients), both studies show marked bone remodelling in the proximal region compared to the diaphysis.

Another possible confounding factor is the surgical approach. Ugland et al. reported significantly increased bone loss around cementless Corail stems implanted using a direct lateral approach than using an anterolateral approach in patients who underwent surgery for a femoral neck fracture [19]. This was evident as both a generalized reduction in BMD (total periprosthetic BMD) and localized bone remodelling in the proximal femur (zones 1, 2, 6, and 7) after 3 months. They reported a continuous decrease in BMD around the femoral stem in the proximal femur for up to 12 months after surgery. The bone density was preserved significantly better in the proximal zones after 3 months with the anterolateral approach, although this advantage greatly waned at the end of the 12-month period. Although we used a completely different approach than did Ugland et al., our results also indicate that bone loss is more pronounced in the proximal region. This finding supports the idea that BMD changes around the stem have a multifactorial aetiology, and a direct comparison between studies may be misleading due to confounding factors.

Mann et al. reported increased and more dispersed periprosthetic bone loss in patients who underwent surgery for a femoral neck fracture than patients who underwent surgery for osteoarthritis [20]. Although patients in both groups underwent total hip arthroplasty, those with a fracture showed reduced BMD in the whole proximal femur (Gruen zones 1, 2, 6, and 7), whereas bone loss in those with arthritis was confined to zones 1 and 7. The results of our hemiarthroplasty series yielded a similar outcome, with the greatest bone loss occurring in the proximal femur. There was relatively little BMD loss, but the reduction remained statistically significant throughout the remaining zones. A direct comparison with Mann et al.'s results is not possible, because they performed only a between-group analysis and did not disclose whether the reduction in periprosthetic BMD was statistically significant compared to the baseline.

The loss of BMD was present in all diaphyseal Gruen zones except zone 3 in our patient group. Although a non-significant increase in BMD in zone 3 might be suggesting a contact between the implant and bone, leading the hypertrophy of the cortex, we did not observe a shift of the stem position on the follow radiographs. However, the evaluations of the stem positioning were done examining the X-rays in the follow-up visits, and we did not measure the shoulder-tip distance and/or a fixed landmark. Thus, the probability of the contact between the implant and bone surface could not be excluded completely.

In addition, the loss of BMD in other diaphyseal zones 4 and 5 might be suggesting a continuous bone loss as a result of patients' age. Since we did not prescribe bone strengthening agents such as calcium and bisphosphonates to our patient group, the continuous bone loss as a result of age might be an expected outcome. However, the relatively greater bone loss on the proximal region might be suggesting the cumulative effect of patient age and cementless implant use on the BMD. On the other hand, since the assessments regarding stem positioning were performed using only X-ray imaging, it should be noted that metaphyseal bone loss might be a result of distal loading.

Although use of cementless implants is related to a more intensive BMD reduction in all Gruen zones, a survey among orthopedic surgeons revealed that 72% of orthopedic surgeons preferred using cementless implants on a regular level [1, 21]. The main reasons for orthopedic surgeons choosing cementless implants over cemented ones are their association with high perioperative morbidity due to hemodynamic and cardiopulmonary complications, and increased mortality in addition to 'cement reaction' or the condition known as bone cement implantation syndrome (BCIS) [22].

The ability of the weakened bone to support the femoral stem in the long term remains a concern. Approximately 30% of highly active elderly patients with a hip fracture experience greater than 2 mm of femoral stem migration following cementless hemiarthroplasty [23]. In our study, no patients experienced symptomatic stem migration that would require revision surgery. One possible explanation is cultural differences; in our country, elderly individuals are mostly confined indoors, except in rural areas, and have a sedentary lifestyle.

Sköldenberg et al. reported good 2-year outcomes with the use of cementless femoral components in 50 patients older than 70 years with a femoral neck fracture [24]. They concluded that cementless stems could be used safely in elderly and osteoporotic hip fracture patients with good results. The patients in our series also achieved good outcomes, with a mean HHS of 74.8, which is slightly lower than the HHS of 82 reported by Sköldenberg. The Biomet cementless femoral components used in both studies have similar designs, except for the collar. The initial stable fixation of porous, coated cementless components may contribute to the good short-term clinical outcome. The difference in the clinical outcome may be because cases of total hip arthroplasty were included in that study, whereas our study was limited to cases of hemiarthroplasty. We found no correlation between BMD and BMI, age, or HHS. Similarly, Hayashi et al. evaluated several factors and reported that BMI was not predictive of bone loss and that the patient HHS was not correlated with the percent change in BMD [13].

An important concern regarding cementless components is the risk of periprosthetic fracture, as highlighted by Sköldenberg et al. [8] and Mann et al. [20]. Both studies included femoral neck fracture patients who underwent total hip arthroplasty and reported a periprosthetic fracture rate of 12%. This high rate of fracture in their follow-up study of the previously published patient series at 5 years caused the authors to warn against the use of cementless designs for the treatment of femoral neck fracture in elderly patients [8]. They noted that the stem remained well fixed despite the significant periprosthetic bone loss, which might explain the high number of late-occurring periprosthetic fractures. Similarly, in Mann et al.'s study, more postoperative bone loss was observed in patients who later experienced periprosthetic fracture than in patients who underwent surgery for osteoarthritis. In our follow-up period, there were no cases of periprosthetic fracture or implant-related complications, perhaps because we excluded patients who required intraoperative cable augmentation. Additionally, all fractures in the previous reports occurred after 2 years (mean 3.4 years). With a longer follow-up period, it is possible that fractures will also occur in our case series.

One would expect BMD to be significantly higher in males than females. One possible explanation is that males with significantly reduced bone density may be prone to femoral neck fracture and thus were clustered in our study. Male patients in our study may not be representative of the general population, and no general conclusion regarding bone quality should be derived from our results.

Calcium supplements and bisphosphonates, and the inorganic pyrophosphate derivatives with increased affinity for bone mineral are used in a wide variety of conditions to prevent bone loss [25]. In our cases, none of the patients received treatment with these agents, since our clinical practice was not implemented on using these agents in this group of patients. Therefore, a future follow-up study of patients treated with cementless implants and BMD preserving agents together might yield different results improving the ratio of bone loss around the femoral stem.

This study has several limitations, among which the short follow-up period is the most important. Periprosthetic fracture related to decreased BMD tends to occur after 2 years. Periprosthetic fracture is a devastating complication, and if a significant increase in the fracture rate is noted, it might indicate the use of cemented components in this age group [26]. The absence of a control group, preferably one in which cemented components were used, is another limitation. In our clinical practice, the use of cemented components is mainly limited to pathological fracture cases.

Conclusion

Cementless hemiarthroplasty for the treatment of femoral neck fracture in elderly patients achieves a good clinical outcome, despite significant bone loss around the femoral stem. The reduction in BMD is more pronounced in the metaphyseal region than in the diaphysis. Studies with longer follow-up periods are needed to evaluate whether the significant bone loss in the proximal femur will result in component loosening or periprosthetic fracture.

Author Contributions MM: surgical operations, writing the manuscript, and supervision of the study. CE: study design and data collection. EAU: study design and data collection. ST: statistical interpretation of the data and supervision of the study. AŞ: assisting surgeon in the surgeries. YÖ: assisting surgeon in the surgeries.

Compliance with Ethical Standards

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

Ethical standard statement The study was approved by the local ethics committee and has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

Informed consent Informed consent was obtained from all participants.

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