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ORIGINAL ARTICLE

A biomechanical comparison of three fixation techniques in osteoporotic reverse oblique intertrochanteric femur fracture with fragmented lateral cortex

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Abstract

Background The treatment of the reverse oblique osteoporotic femur fractures is still problematic and can be complicated especially that are accompanied by a fragmented lateral cortex.
Aim The aim of this study was to compare three different internal fixation methods in the osteosynthesis of osteoporotic reverse oblique intertrochanteric femur fracture models with a fragmented lateral cortex.
Study design Biomechanical experiment study.
Methods A total of 24 osteoporotic femur models were obtained and divided into three groups [Group A: Proximal femoral nail (PFN), Group B: 95° angled blade plate (ABP), and Group C: proximal femoral anatomic locking plate (PFLP)] with each group which include eight bones. A standard fracture configuration was created as a reverse oblique intertrochanteric fracture and fixed with these implants. After fixation, all femur constructs were tested with an Instron 5800R tester (Instron, Canton, MA) in the biomechanics laboratory with axial loading and bending forces to assess axial and rotational stiffness and failure load. Displacement over 10 mm and angulation greater than 10° in the fracture line were considered as failure.
Results In all tests, ABP had statistically poorer results in comparison to the PFN and PFLP group. PFLP fixation had better biomechanical fixation results in comparison to the PFN group, although the results were not statistically significant.
Conclusion Orthopaedic surgeons should keep in mind that lateral cortex comminution brings further instability to these reverse oblique intertrochanteric osteoporotic fractures and high rates of failure may be encountered due to this instability. PFLP fixation may be an alternative fixation method biomechanically for these instable fractures.

Keywords Fragmented lateral cortex · Locking plate · Osteoporotic saw bone · 95° angled blade plate · Proximal femoral nail

Introduction

Proximal femoral fractures are relatively common in elderly individuals and are associated with low-energy trauma due to osteoporotic and fragile bones with the common mechanism of falling on the affected hip. The incidence of these type fractures is increasing and is thought to double over next 25 years due to the aging of population [1]. Stability of the fracture pattern is major determinant in choosing treatment alternatives and choosing the appropriate implant for successful osteosynthesis. Pertrochanteric fractures are thought to be unstable if comminution of calcar femorale, subtrochanteric extension, and reverse obliquity is present. A variety of osteosynthesis materials such as dynamic hip screws and proximal femur nails can be used in the treatment [2, 3].

The treatment of the reverse oblique osteoporotic femur fractures is still problematic and can be complicated especially in cases accompanied by a fragmented lateral cortex [4]. In spite of the fact that new-generation proximal femur nails are efficient in treatment, osteosynthesis success in osteoporotic patients is still questionable and using alternative implants such as anatomic proximal femur locked plates which have been studied [5].

The aim of this study was to compare three different internal fixation methods in the osteosynthesis of osteoporotic

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reverse oblique intertrochanteric femur fracture models with a fragmented lateral cortex.

Materials and methods

A total of 24 osteoporotic femur models (Sawbones, SKU: 1130−130, Malmoe-Sweden) were obtained and randomly divided into three groups [Group A: Proximal femoral nail (PFN), Group B: 95° angled blade plate (ABP), and Group C: proximal femoral anatomic locking plate (PFLP)] with each group which include eight bones. For this biomechanical study, especially osteoporotic femur model was chosen, because unstable pertrochanteric fractures are commonly seen in elderly individuals with osteoporosis. We intended to compare the biomechanical properties of three different osteosynthesis materials especially on osteoporotic bones.

Bone models were prepared as a standard three fragmented (reverse oblique peritrochanteric fracture with broken lateral wall as another fragment) fracture configuration (AO/Orthopedic Trauma Association type 31/A3.3). Our fracture model had two fracture lines. The first line was started from lesser trochanter with 30 degrees lying distally to the lateral wall. The second fracture line was started from the tip of the trochanter major, and reached the distal reverse oblique fracture line lying parallel and 1 cm to the lateral femoral cortex. With this line, the fracture became tripart with a broken lateral wall that both femoral cortices were involved as a reverse oblique fracture pattern (Fig. 1). All of the models were prepared with a similar fracture configuration with an oscillating saw over the specific template that was previously mentioned. After the reduction of fragments with temporary Kirchner wires and selected implant that was suitable for the surgery was used for fixation. All fixations were performed in the operating room by the same surgeon using the standard instrumentations under fluoroscopy

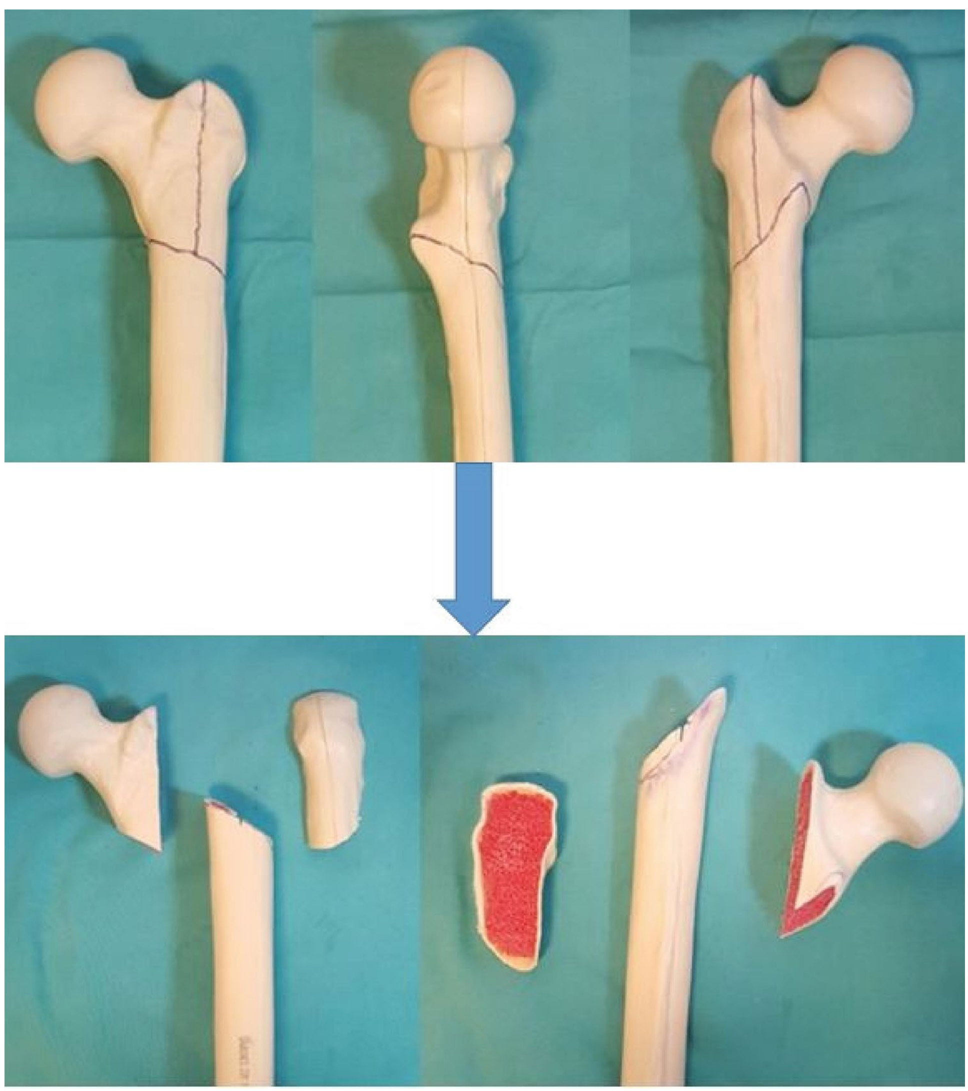

Fig. 1 Reverse oblique bone model with lateral wall defect

control. At the end of the fixation, each construct was tested by X-ray to ensure optimal implant position.

Proximal femoral nails (PFN) (InterTAN® -Smith & Nephew, Memphis, TN) were used for Group A. After insertion of the guidewire into the medulla, medulla was reamed and 125° neck angled 11.5 mm × 18 mm sized femoral nail was inserted to the medullary canal. Proximal screws (105 mm lag screw and 100 mm compression screw) were placed as usual with compression of the fracture line and system was locked after distal screw fixation.

95-degree angled blade plates (ABP) (Ortopro, Turkey) were as Group B. After insertion of a Kirchner wire via 95° condylar plate guide under fluoroscopic control, lateral cortex was drilled and the chisel guide was applied as usual. A 95° plate (90 mm blade with 9 holes) was pushed to the prepared channel with light hammer blows and fracture was fixed with 5 screws (Fig. 2).

Proximal femoral anatomic locking plate were used (PFLP) (PERI-LOC 4.5 mm, Smith & Nephew, Memphis, TN) for Group C. After placement and temporary fixation of plate (234 mm with 15 holes) with Kirschner wires, the plate was fixed with three locked screws that directed towards the femoral head and four locked screws for the femoral shaft (Fig. 3; Table 1).

Biomechanical testing was performed using an Instron 5800R (Instron, Canton, MA) material testing machine. The load was applied to the head of the femur through a custom-made head adaptor acting as acetabulum for force

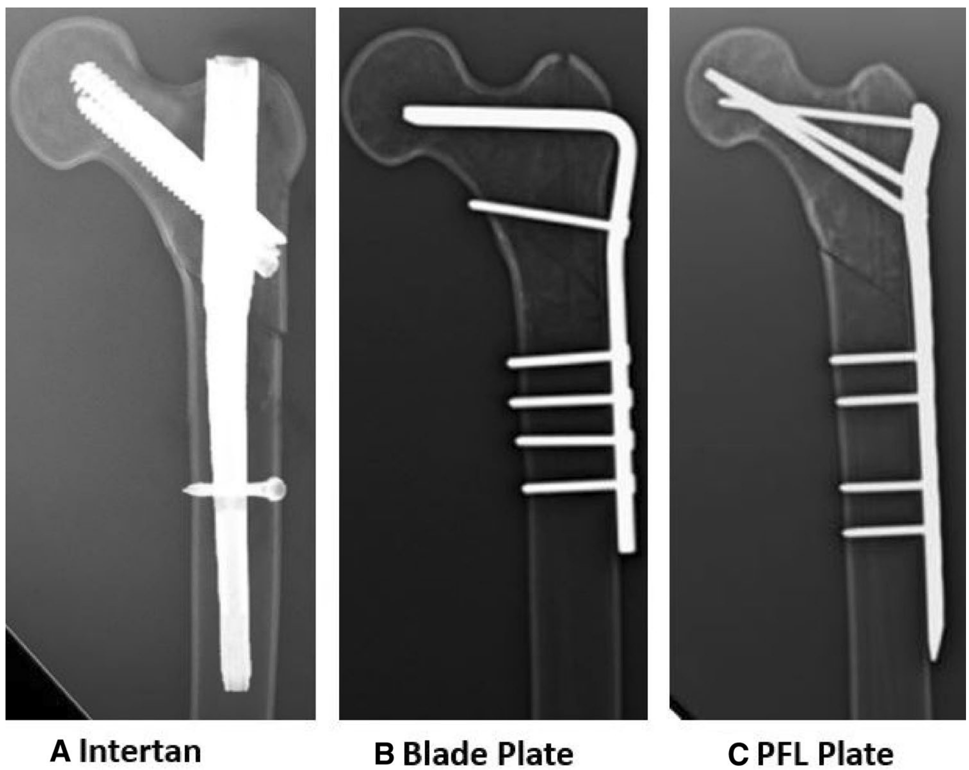

Fig. 2 Implant construct radiographs. **a** Intertan. **b** 95° angled blade plate. **c** Proximal femur locking plate

Table 1 Characteristics of the fixation materials were shown

Group	Fixation type	Length	Proximal fixation	Shaft/distal fixation
Group A PFN (Intertan®/S&N)	Proximal femoral nail	11.5 mm × 18 cm	105 mml screw/100 mm compression screw	40 mm locking screw
Group B ABP (Ortopro®)	95° angled blade plate	16 cm	90 mm blade and 5.0-mm locking screw	40–45 mm and 5.0 mm solid bicortical locking screws
Group C PFLP (Peri-loc®/S&N)	Proximal femur locking plate	234 mm	95 mm (hole 1), 110 mm (hole 2) and 115 mm (hole 3) 7.3-mm cannulated proximal locking screws	40 and 4.5 mm solid bicortical locking screws

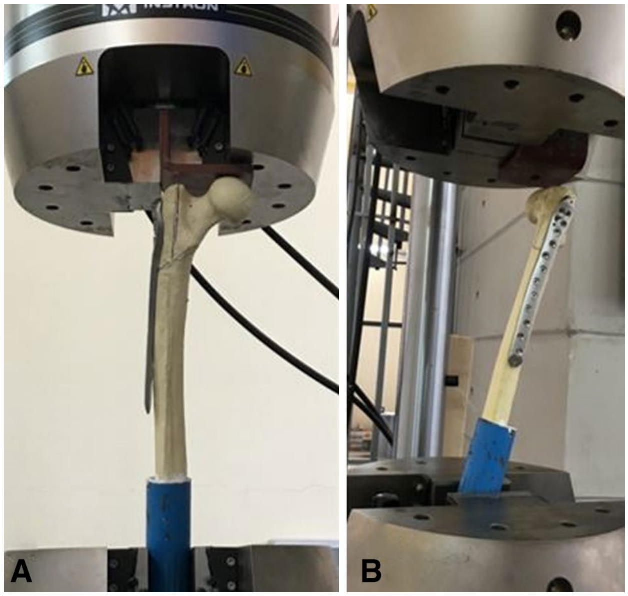

Fig. 3 **a** Axial loading test and **b** axial loading test at 15 degrees flexion

transmission. Each specimen was potted in a metal tube with using plaster and tested, while the specimen was vertical at the sagittal and coronal planes. Each specimen underwent axial and 15° flexion axial testing along with cyclic axial loading to failure for determining irreversible deformation (Fig. 3).

Each construct undergone four different experimental procedures. The initial stiffness testing was performed first and consisted of loading each specimen to 100 N at a rate of 5 mm/min. Second, the axial cyclic loading test was applied with the force from 75 to 125 N, at 3 Hz frequency for 1000 cycles. Third, the construct was angled 15 degrees flexion to simulate single support stance phase of walking and cyclic loading was applied with the force from 75 to 125 N, at 3 Hz frequency for 1000 cycles, and final stiffness was defined. The initial axial stiffness and final stiffness were calculated from the linear portion of the load–displacement curve, respectively. Finally, constructs were loaded to failure in vertical position with a starting load of 50 N at the rate of 10 mm/min. Displacement over 10 mm in fracture site and angulation over 10 degrees were considered as failure. Failure load of each implant-femur construct was recorded. At the end of each cycle, the angulations and translations were photographed using optic cameras (Vic-Snap 2010 Image Acquisition; Correlated Solutions, Columbia, SC). After failure of the models with cyclic loading, a preload pressure of 50 N was applied with a 0.1 mm/s velocity until the model had failed with continuous loading. Time, loading, dorsal angulation, cycle number, and camera signals were concurrently monitored and recorded. Data from the optic camera in the measurement system were analyzed using digital image correlation software (Vic-3D 2010; Correlated Solutions).

Statically analyses

The data was analyzed using SPSS (Statistical Package for the Social Sciences) 22.0 version for Windows (SPSS Inc., Chicago, IL). Comparisons were made by one-way ANOVA test and the significance value was accepted as $p < 0.05$ for 95% confidence interval. For comparison between three groups, Tukey's range test was used among post hoc tests.

Results

In the biomechanical analysis, the initial stiffness values were 71.7 ± 13.5 N m/m for PFN group, 46.5 ± 13.5 N m/m for ABP group, and 82 ± 34 N m/m for PFLP group. Although the initial stiffness value was higher in the PFLP group, there was no statistical difference in comparison to the PFN group ($p = 0.78$). However, there was a significant difference between the ABP group and PFLP group. ($p = 0.005$) However, initial stiffness results revealed a significant difference between PFN group and ABP group ($p = 0.038$).

The cyclic axial stiffness of constructs showed similar results as the initial stiffness. The mean axial stiffness was 74.6 ± 14.4 N m/m for PFN group, 48.5 ± 13.8 N m/m for ABP group, and 77.4 ± 10.5 N m/m for PFLP group. Similarly, ABP group had poorer results in axial stiffness in comparison to PFN ($p = 0.001$) and PFLP ($p < 0.001$). However, the comparison of results between PFLP and PFN groups did not reveal significant difference ($p = 0.673$).

Axial loading test at 15 degrees flexion had similar results that were obtained with the initial and axial stiffness. Stiffness at 15 degrees of flexion was 67.7 ± 14.4 N m/m for PFN group, 39.2 ± 14.2 N m/m for ABP group, and 79.3 ± 24.9 N m/m for PFLP group. PFLP group had better results that statistically significant in comparison to the ABP group ($p < 0.001$). There were no statistical difference in comparison to the results of PFN group ($p = 0.225$).

Seven of the eight constructs in PFN group, eight of the eight constructs in PFLP group, and eight of the eight constructs in ABP group failed as more than 10 mm displacement of the intertrochanteric fracture line to the varus position. One of the constructs in PFN group failed as fracture of the femoral diaphysis beneath the distal end of the nail.

Finally, all constructs were loaded until failure occurs and results were recorded. The mean failure load was 230.2 ± 35.8 N m/m for PFN group, 187.3 ± 28.7 N m/m for ABP group, and 243.2 ± 33 N m/m for PFLP group. Although PFN ($p = 0.016$) and PFLP group ($p = 0.003$) had better results in comparison to ABP group, there were no statistical differences between PFN and PFLP group regarding failure loads ($p = 0.435$) (Table 2).

Discussion

The most important data that we found in this study were that the ABP group had poorer biomechanical properties and the PFLP group was the best way for fixation, although the differences were not statistically significant in comparison to the PFN group in the model of reverse oblique osteoporotic fracture with fragmented lateral cortex. The incidence of these type fractures is increasing and is thought to be doubled over next 25 years due to the aging of population. Obtaining a stabile osteosynthesis is difficult because of osteoporosis-related technical factors that increases reoperation risk of patients especially in osteoporotic reverse oblique fractures with fragmented lateral cortex [6].

Pertrochanteric fractures constitute 30.2% of all osteoporotic hip fractures [7]. Several studies have shown that osteosynthesis reduces patient mortality in the treatment of intertrochanteric hip fractures. As osteosynthesis material; many implants have been designed and have been using such as ender nails, dynamic hip screws, fixed angled plates, proximal femoral nails, and proximal femoral plates [4, 7]. In recent years, third-generation proximal femoral nails have been using widely for hip fractures and proximal femur anatomic locking plates were emerged as an alternative method [8].

Although many classifications have been using for these fractures, Evans and AO classification are two most commonly used ones [9]. The number of fractured fragments, discontinuity or absence of the posteromedial support, the severity of osteoporosis, and the presence of the fragmentation of the lateral cortex are factors affecting instability and prognosis [4, 6]. In one of the studies that was evaluated lateral cortex fragmentation, the authors evaluated the clinical outcomes of 214 patients who had intertrochanteric fractures and had been operated with dynamic hip screw. The authors stated that they had a 22% reoperation rate in their series in patients with lateral cortex fragmentation [10]. In this respect, a reverse oblique fracture model with lateral cortex fragmentation was created in our study.

Many studies have been conducted about the intertrochanteric femur fractures over the years and it has been reported that systems providing intramedullary fixation especially for unstable fractures provide better results than dynamic hip screws or fixed angled plates [11, 12]. Sadowski et al. reported that the proximal femoral nail treatment results were better than 95 degree fixed angled plate treatment results and they were recommended to use proximal femoral nails in osteosynthesis of fractures that were classified as AO/OTA-31-A3 reverse oblique intertrochanteric femoral fractures [13]. Kumar et al. reported their series of prospectively followed 50 hip fracture patients and stated that proximal femoral nail treatment results were better than dynamic hip screws in the osteosynthesis of reverse oblique osteoporotic intertrochanteric femoral fractures [14]. In another clinical study that compared proximal femoral nails and minimally invasive proximal femoral locking plates in instable intertrochanteric femoral fractures, the authors reported no significant differences in complication between the two groups after 1 year of follow-up [15]. Nevertheless, Streubel et al. reported their 64 patients (aged 21–94 years) retrospectively and concluded that mechanical failure and reoperation rate were more frequent in proximal femoral plates in comparison to the proximal femoral nails [16]. In addition, Johnson et al. had used proximal femoral locking plates in 29 patients with unstable fractures and reported a short-term unacceptably high failure rate of 41.4% [17]. In a large case series, the authors investigated the clinical results of 111 patients with unstable proximal femur fractures that stabilized with a PFLP. They concluded that 34% of the patients had needed secondary surgeries related with failed fixation and nonunion [18]. In a recent study, the authors investigated the effect of anatomic reduction of fractures in cadaveric bone that were fixed with PFLP, and concluded that proper placement of the proximal screws in anatomically reduced fractures led to significantly higher construct stability and can reduce failure rate [19].

In the literature, there were no studies that were evaluating a homogeneous population of patients in which factors such as age and bone quality are eliminated. Ma et al. reported a cadaveric study of the reverse oblique fracture

Table 2 Biomechanical results of the constructs were shown

	PFN group		ABP group		PFLP group	
	Mean	SD	Mean	SD	Mean	SD
Initial stiffness	71.7	±13.5	46.5	±13.5	82	±34.3
Cyclic axial stiffness	74.6	±14.4	48.5	±13.8	77.4	±10.5
Axial loading test at 15 degrees flexion	57.7	±14.4	39.2	±14.2	79.3	±24.9
Failure load stiffness	230.2	±35.8	187.3	28.7	243.1	±33

model. The authors compared PFN and PFLP treatments (Eight cadavers on each group) and reported that PFN treatment was superior to the PFLP treatment biomechanically. However, the authors reported that cadaveric bones were not osteoporotic when assessed by dual-energy X-ray absorption (DEXA) [20]. Some authors investigated and compared the biomechanical properties of PFN and PFLP fixation in hip fractures [21, 22]. In these studies, the authors analyzed cadaveric bones that were not osteoporotic and uniform or third-generation synthetic bones that were not represent an osteoporotic model. They concluded that PFN had higher biomechanical properties in comparison to the PFLP [21, 22]. Although some studies reported undesired outcomes both clinically and biomechanically, some authors reported good results with PFLP [5–23]. This non-concurrence may be related to the non-homogeneous patient populations in clinical studies or factors that may be related to the materials that may affect the outcome of biomechanical studies.

In our study, to represent the accurate patient population, an osteoporotic fracture model was preferred because of the high frequency of this fracture in the geriatric population. Due to our clinical observations and some problematic cases that we encountered especially patients with lateral cortex fragmentation, we want to evaluate this factor biomechanically. In addition, we tried to create an instable reversed oblique fracture model that had an additional instability with lateral cortex fragmentation and we tried to test biomechanical properties of these most commonly chosen implants (ABP, PFN, and PFLP) for this study. In our experiments, loss of fracture fixation was observed under much lower forces due to the biomechanical properties of osteoporotic bone model. However, the best stiffness and failure load values were obtained with PFLP fixation in comparison to the ABP and PFN group, but the difference between these values was not statistically significant compared with PFN group. The biomechanical results of ABP fixation were insufficient in this osteoporotic reverse oblique fracture model. Especially, third-generation PFN implants have been most commonly chosen implant for these instable fractures in recent years; however, especially for the fractures with lateral cortex fragmentation, high rates of failure can be encountered. PFLP is an alternative implant that have been using for this cases by some authors [15, 16]. In our study, PFLP had equivalent results to the PFN.

Our study is the first study to compare these three fixation materials on the osteoporotic bone model in the literature. Although this synthetic bones were not used as a standard biomechanical testing material, we used this specific osteoporotic bone model to represent the geriatric patients' characteristics homogeneously. However, the lack of the evaluation of the soft-tissue factors in application of implants and the lower stiffness results in comparison to the previous studies are the main problems in our biomechanical study for clinical relevance. In addition, we could not analyze and compare the rotational stability of the constructs due to the limitation of the biomechanical laboratory.

Conclusion

ABP fixation had insufficient biomechanical properties in comparison to the PFN and PFLP fixation. PFLP fixation is an alternative for these fractures and we had higher biomechanical fixation results in comparison to the PFN group, although the results were not statistically significant. Orthopaedic surgeons should keep in mind that lateral cortex comminution brings further instability to these revers oblique intertrochanteric osteoporotic fractures and high rates of failure may be encountered due to this instability. PFLP fixation may be an alternative fixation method biomechanically for these instable fractures. Nevertheless, more clinical trials should be done to evaluate the effectiveness of these implants.

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Compliance with ethical standards

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

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