



Efficacy of poller screw in addition to lag screw in the treatment of intertrochanteric fractures with proximal femoral nail: a biomechanical evaluation

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Abstract

Purpose The most common type of failure in treating intertrochanteric fractures with proximal femoral nails is cut-out due to varus collapse. We aim to evaluate the effect of the poller screw applied to the proximal fragment and the lag screw on varus collapse and stability in intertrochanteric fractures.

Methods An unstable intertrochanteric fracture model without medial support was simulated in 20 synthetic femur models. In the poller screw group, in addition to the lag screw, pole screws were applied to the proximal fragment superior and inferior to the lag screw. In the progressive cyclic loading test, starting from 100 N, the loading was increased by 50 N in each cycle, and the test was continued until the maximum load at which failure occurred as a result of conditioning cycles and progressive cyclic loading tests, stiffness, type of failure, force at failure, lag screw displacement, and varus collapse were recorded.

Result The average stiffness was found to be 124.705 N/mm in the poller screw group and 102.77 N/mm in the control group ($P < 0.001$). The maximum load to failure was 1897.10 N in the poller screw group and 1475.20 N in the control group ($P < 0.001$). The average displacement of the lag screw within the femoral head was 0.85 mm in the poller screw group and 3.60 mm in the control group ($P < 0.001$).

Conclusion As a result, it has been shown that poller screws applied around the lag screw increase fixation stiffness and reduce varus collapse.

Keywords Intertrochanteric fracture · Poller screw · Biomechanical study · Proximal femoral nail

Introduction

The incidence of intertrochanteric fractures increased with prolongation of life expectancy [1]. The annual incidence of hip fracture is predicted to be 6.3 million people in 2050 [2]. In treating intertrochanteric hip fractures, the proximal femoral nail (PFN) is widely used because it allows early weight bearing, and its load-bearing capacity is superior to extramedullary fixation devices [3]. Despite its biomechanical advantages, implant and fixation failure rates are 22.3%, especially in comminuted hip fractures without medial cortical support [4, 5]. It has been demonstrated that the medial calcar has essential roles in the fixation of intertrochanteric

fractures, both in load transfer and in structural support of fixation [6, 7]. As a result of biomechanical studies, it has been shown that fixation stability is significantly reduced in intertrochanteric fractures without medial calcar integrity [8, 9]. In intertrochanteric femur fractures without medial calcar support, cable applications have been made for the fixation of the medial calcar, and their biomechanical superiority has not been demonstrated [10]. It has been shown that fixation stability is increased due to cement augmentation of the lag screw in intertrochanteric femur fractures without medial calcar support [11]. Although the cemented augmented lag screw has biomechanical advantages, it has undesirable effects, such as cement leakage to unwanted places and thermal osteonecrosis [12, 13]. It increases fixation stability in intertrochanteric fractures without medial calcar support [14, 15]. Our study aimed at biomechanical evaluation of the effects of poller screws applied around the lag screw on fixation strength, stiffness, survival rate, failure

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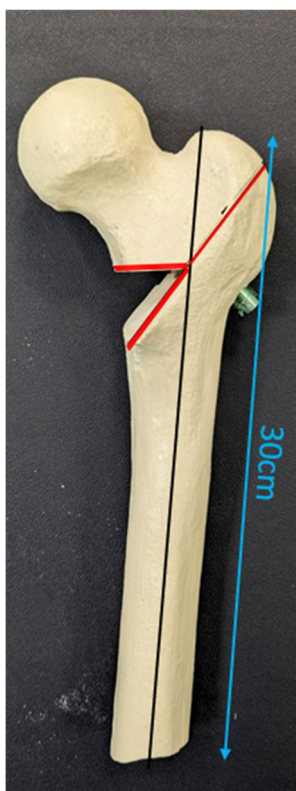
load, and failure mechanism in intertrochanteric fractures without medial calcar support.

Methods

Specimen preparation

A total of 20 synthetic femur osteoporotic models (LD2350.01, cortical low density/soft cancellous bone, Synbone AG, Neugutstrasse 4, 7208 Malans, Switzerland) were used for the study [16, 17]. Synthetic bones were randomly divided into two groups. In both groups, proximal femoral nailing was performed before osteotomy for the fracture model to simulate AO/OTA 31A-2.2. The specimens were fixed with a single lag screw proximal femoral nail (Zimed Medical Turkey, Simple lock proximal femoral nail system). The manufacturer's guide applied the proximal femoral nail. A 200 mm long and 10 mm wide PFN was applied to the samples. The lag screw was applied with the guide system in all samples in the center-center position according to the Cleveland-Bosworth quadrants [18]. The 100 mm lag screws were applied to all samples under axial and anterior–posterior fluoroscopic control with a tip apex distance (TAD) of 15 mm [19]. The TAD measurement was corrected according to the actual length and width of the lag screw. Distal locking of all nails was provided with one static screw.

Fig. 1 Simulation of unstable intertrochanteric fracture (AO/OTA 31-A2.2) and bone cuts in sawbones model



Implants were removed from all synthetic bones, and osteotomy was performed for the AO/OTA 31-A2.2 fracture model using custom templates (Fig. 1).

All osteotomies were performed using an oscillating saw. The first osteotomy line was created 1 cm below the greater trochanter towards the intertrochanteric line towards the base of the trochanter minor. The second osteotomy was made to the top of the trochanter minor from the intersection of the line drawn in the middle of the diaphysis and the first osteotomy line. The inferior wedge was removed [11, 20, 21]. After osteotomy, proximal femur nails were reapplied. In the poller screw applied group, the first poller screw was used immediately inferior to the lag screw, 1.5 cm to the intertrochanteric fracture line. The second poller screw was applied superior to the lag screw, 4 cm from the intertrochanteric fracture line, proximal to the head-neck junction (Fig. 2). Due to the variability in the size of the medial calcar fragment in intertrochanteric fractures, it is not possible to make standardization regarding poller screw application. Due to the clinical variability in the dimensions of the medial calcar fragment, in our study, a distance of 1.5 cm was preferred, as close to the fracture line as possible and able to withstand the loading during biomechanical tests, to resist varus collapse in the samples in which the standard fracture model was created.

Synthetic bones were cut 30 cm distal to the trochanteric tip and embedded with polyurethane resin (Technovit 4006; Heraeus Kulzer GmbH, Wehrheim, Germany) in custom metal cylinders 10 cm high [21, 22]. Synthetic femurs were positioned at 25° of adduction in the coronal plane and 10°

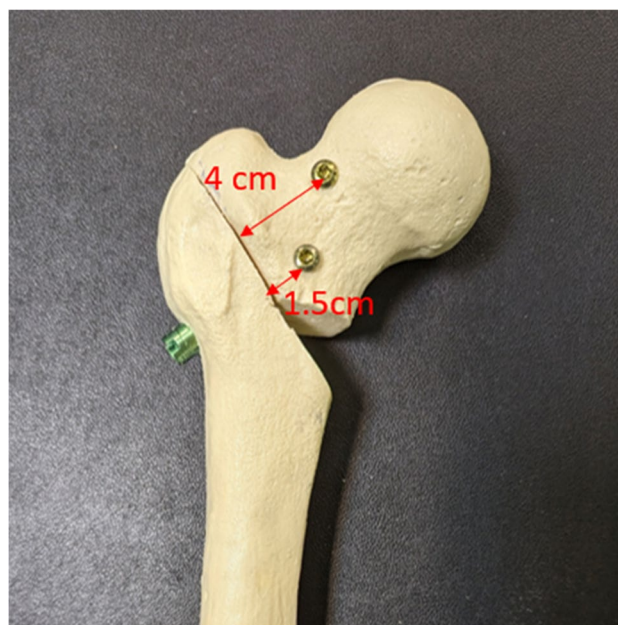


Fig. 2 Inferior and superior poller screw application

of posterior flexion in the sagittal plane to compare with previously published studies and to simulate the bending forces and rotational moment in the coronal and sagittal planes of the single leg in the stance phase in axial loading [21, 23–25] (Fig. 3). Loading tests were performed on a Shimadzu AG-I 10KN (Kyoto, Japan) mechanical testing machine.

Test protocol

Cyclic and progressive loading protocols are commonly used in biomechanical studies of intertrochanteric fractures. The cyclic loading protocol is generally designed to be 10,000 loading cycles, considering the number of steps the patient will take during the 6-week recovery period [11, 26, 27]. Considering the variability of the healing time of intertrochanteric fractures and the change in the load sharing between bone and implant during the healing process, the cyclic loading protocol does not reflect reality [28, 29]. The time required to implement the cyclic loading protocol is very long. Progressive loading protocol, which has been applied in many studies before, was preferred as the test protocol [10, 17, 30, 31]. After all samples were placed in the testing machine, complete contact with the testing apparatus was ensured by



Fig. 3 Biomechanical testing setup. The specimen is mounted in a 10 cm custom metal cylinder with a 25° adduction at the coronal and 10° posterior flexion at the sagittal plane

applying a preload of 100 N. Following preload, non-destructive conditioning cycles were applied, increasing 100 N to 700 N for ten cycles [32]. The stiffness of the construct was calculated from the load/standard travel curve from the last three non-destructive conditioning cycles [33]. The test phase consisted of cyclic loading with a constant speed of 4.6 mm/s, a rate between 100 N, and the maximum force that increased at 50 N at each cycle until failure [17]. The failure led to a load drop corresponding with an irreversible negative slope in the vertical force–displacement curve [17, 21]. The peak of this curve was defined as the ultimate failure load.

The study evaluated failure types, ultimate failure load, and standard stiffness. Failure types were recorded as implant deformation, fracture around the distal locking screw, and cut-out. As a result of the test, varus collapse occurring in the intertrochanteric fracture line was evaluated in all samples. As a result of the load-to-failure test, axial displacement of the tip of the lag screw was assessed by applying osteotomy to the femur intertrochanteric fragment in the coronal plane in all samples. After the osteotomy, the distance between the initial position of the lag screw tip and its location at the last position after the load-to-failure test was measured.

Statistical analysis

Statistical analysis was performed using Statistical Package for Social Sciences version 24.0 software in the statistical analysis of the study for Windows (IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp. USA). Descriptive statistics are expressed as numbers, mean, and standard deviation. Several observations of categorical variables were given as *n*. The normality of the variables was tested with Kolmogorov–Smirnov and Shapiro–Wilk tests. The *t*-Student test was used for parametric, and the U Mann Whitney test was used for non-parametric evaluation. $P < 0.05$ was considered statistically significant.

Results

All samples in both groups survived the 700 N conditioning cycle. No deformation or breakage was observed in any implant as a result of the load-to-failure test. No fracture was observed around the poller screw in any sample in the poller screw group. The average stiffness calculated from the last three conditioning cycles was found to be 124.705 N/mm (SD 18.5) in the poller screw group and 102.77 N/mm (SD 22.3) in the control group (Fig. 4).

A statistically significant difference was observed between both groups regarding stiffness ($P < 0.001$). The

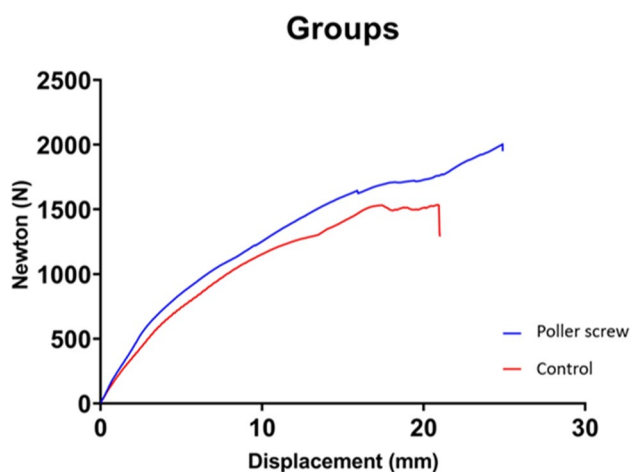


Fig. 4 Typical axial load–displacement curves. Poller screw group; control group

maximum load to failure was found to be 1897.10 N (SD 165.68) in the poller screw group and 1475.20 N (SD 178.18) in the control group ($P < 0.001$) (Table 1).

When both groups were compared in terms of maximum load to failure, it was found to be 33.3% higher in the poller screw group. When the average displacement of the lag screw within the femoral head was evaluated as a result of the load-to-failure test, it was found to be 0.85 mm (SD 0.78) in the poller screw group and 3.60 mm (SD 1.8) in the control group ($P < 0.001$) (Fig. 5).

The displacement of the lag screw in the head in the poller screw group was found to be 4.5 times lower than in the control group. In the poller screw group, fracture development at the distal part of the nail was observed in 5 samples, impaction on the femoral head without varus collapse was observed in 3 samples, and cut-out was observed in

Table 1 Comparison of the groups

	Poller screw <i>n</i> = 10	Control <i>n</i> = 10	<i>P</i>
Load to failure (Newton)	1897.10 ± 165.68	1475.20 ± 178.18	0.004
Stiffness (N/mm)	124.5 ± 18.5	102.77 ± 22.3	0.003
Lag screw displacement (mm)	0.85 ± 0.78	3.60 ± 1.8	<0.001
Varus collapse (°)	2.13 ± 0.38	11.66 ± 0.62	<0.001
Failure types			
Cut-out	2	10	0.003
Fracture around to distal locking screw	5	0	<0.001
Impaction at the femoral head without varus collapse	3	0	<0.001

Fig. 5 Dislocation at the failure point (control group). **a** Varus collapse. **b** Displacement of the lag screw within the femoral head

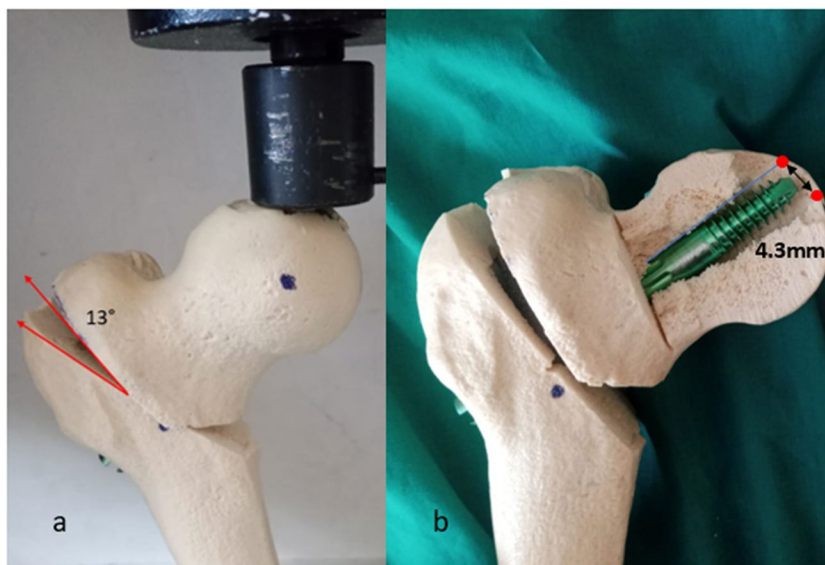




Fig. 6 Failure types after load to failure test. **a** The fracture occurred around to distal locking screw at the poller screw applied group. **b** Lag screw cut-out due to advanced varus collapse in the control group

2 samples. In the control group, cut-out developing due to varus collapse was observed in all samples (Fig. 6).

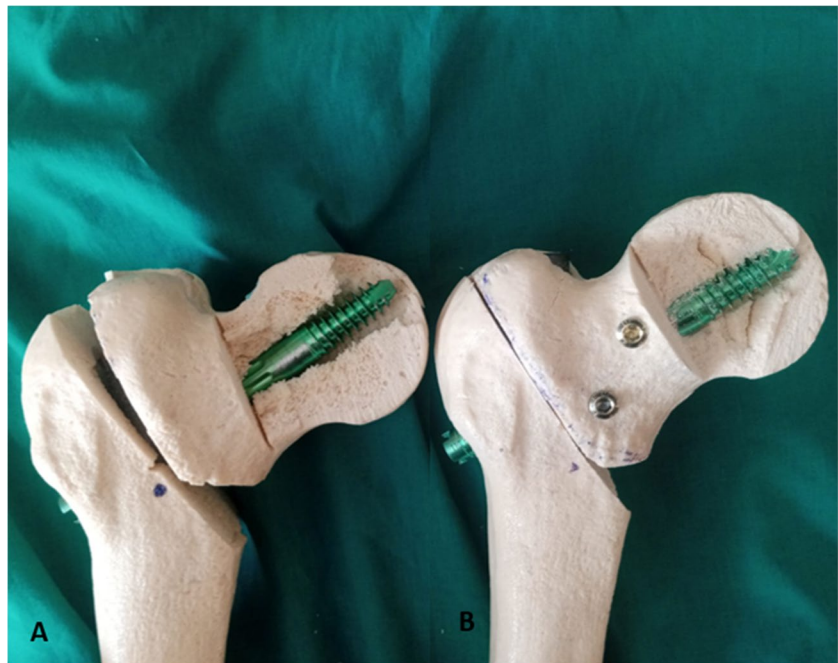
As a result of the load-to-failure test, an average of 2.13° (SD 0.38) of varus angulation developed in the samples in the poller screw group, while it developed 11.66° (SD 0.62) in the control group. A statistically significant difference was observed between both groups in terms of varus collapse ($P < 0.001$) (Fig. 7).

Discussion

The ideal implant in the surgical treatment of intertrochanteric fractures should allow stable fixation by sharing load until the fracture heals. Intramedullary implants are widely preferred due to their many biomechanical advantages [34]. Despite the advantages of

intramedullary nails, complication rates vary between 3 and 14% [4]. We hypothesized that poller screws applied in addition to lag screws in treating unstable intertrochanteric fractures would increase the fixation power. As a result of the research, it was found that the construct stiffness in the poller screw applied group was significantly higher. As a result of the poller screw application, the maximum load values at the point of failure were found to be 33.3% higher. The main failure after PFN application in unstable intertrochanteric fractures is cut out due to varus collapse [35]. As a result of the load failure test, it was observed that the poller screws restricted the movement of the lag screw in the femoral head and created resistance against varus collapse. Lack of medial cortical support appears as an important risk factor for mechanical failure in treating unstable intertrochanteric fractures with PFN [9, 15]. Although single-lag PFNs provide sufficient biomechanical stability in treating stable intertrochanteric fractures, they may be insufficient in intertrochanteric fractures without medial calcar support [36]. Dual integrated lag systems have better resistance to lag screw displacement and varus collapse in unstable intertrochanteric fractures without medial calcar support [37, 38]. In our study, the loading and deforming forces occurring between the lag screw and the metaphyseal bone during the load-to-failure test due to poller screw application were transferred to the anterior and posterior cortex of the intertrochanteric fragment. In our study, no fracture was observed in the intertrochanteric fragment due to the application of poller screws in the anterior–posterior cortices in any sample. As a result of the finite elemental analysis conducted by Zheng et al. [39], it was shown that as a result of single lag PFN application in the intertrochanteric fracture model without medial calcar support, Von-mises stresses were concentrated in the tip of the lag screw and the medial calcar region, and as a result of cement augmentation, Von-mises stresses and the concentration in the tip of lag screw decreased. In another study by Fensky et al. [11], it was shown that the fixation stiffness increased significantly as a result of cement application, the movement of the lag screw in the femoral head was restricted, and the resistance to varus collapse was increased by providing more homogeneous load transfer. Similar to our study, the load transfer was distributed to the anterior and posterior cortex of the intertrochanteric fragment in addition to the metaphyseal bone with the poller screw application. Current nail designs are available to increase stability in unstable intertrochanteric fractures. In these nail designs, in addition to the lag screw, triangular support is provided with screws applied

Fig. 7 Dislocation occurs in the samples due to the load-to-failure test. **A** Control group, **B** poller screw group



over the nail, and the movement of the femoral intertrochanteric fragment is restricted during loading [40, 41]. In the method we developed, in addition to the currently widely used single lag systems, the movements of the lag screw are restricted by the application of 2 poller screws, and the intertrochanteric fragment and lag screw are supported despite varus displacement. Poller screws have increased stability during intramedullary nail application in fractures located in the large metaphyseal region [42–44]. Kwak et al. [45] showed that applying poller screws to the subtrochanteric region of the femur to eliminate the incompatibility between the wide femoral canal and the nail in unstable pertrochanteric fractures increased stability. In our study, it was shown that poller screws applied to the intertrochanteric fragment increased stability. There are some limitations in our study. The main limitation of our study is that there is no clinical or anatomy study related to the application of poller screws in intertrochanteric fractures. No research on poller screw application in intertrochanteric and pertrochanteric fractures includes data on safe zones or anatomical structures at risk. Although there is no research in the literature on the application of pertrochanteric poller screws in intertrochanteric fractures, when clinical and cadaveric studies on safe portal applications in hip arthroscopy are evaluated, we think that anterior and mid-anterior portals, whose reliability has been proven, can be used for poller screw application [46, 47]. Due to the lack of literature, a cadaver dissection study is being carried out on the reliability of block screw applications in pertrochanteric fractures. Another limitation

is that although cyclic loading tests better simulate the physiological loading during the post-surgical recovery period, a progressive loading test was used in our study, as used in many studies [10, 16, 17]. The sample size in our study was ten samples in each group, corresponding to other studies in the literature [16, 21, 37]. In our study, since the effectiveness of the poller screw against varus collapse was investigated, only the axial load-to-failure test was performed, and rotational stability or cyclic tests in different planes were not performed.

Conclusion

As a result of this *in vitro* biomechanical study, it has been shown that poller screws applied around the lag screw increase fixation stiffness and reduce varus collapse. It has been demonstrated that poller screws used to the proximal intertrochanteric fragment reduce the displacement of the lag screw within the femoral head. Further clinical studies are needed to demonstrate the effectiveness of poller screws in intertrochanteric fractures. Clinical studies are required to reveal the applicability and reliability of poller screws to the intertrochanteric fragment. Anatomy cadaver studies are needed to show the anatomical structures at risk during poller screw application.

Author contribution Conception and design: LH. Acquisition of data: LH, MFC. Statistical analysis: LH. Analysis and interpretation of data: LH, MFC, HC. Drafting the article: LH, MFC, HC. Critically revising the article: LH, MFC. Administrative/technical/material support: HC.

Study supervision: LH. Reviewed submitted version of manuscript: LH, MFC, HC.

Data availability The authors declare that data will be made available upon reasonable request.

Declarations

Conflict of interest The authors declare no competing interests.

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