Biomechanical Evaluation of Extramedullary Versus Intramedullary Reduction in Unstable Femoral Trochanteric Fractures

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Abstract

Introduction: The failure rate of operations involving the cephalomedullary nail technique for unstable femoral trochanteric fractures is 3-12%. Changing the reduction strategy may improve the stability. This study aimed to confirm whether reducing the proximal fragment with the medial calcar contact, as opposed to utilizing an intramedullary reduction, would improve the stability of such fractures. **Materials and Methods:** The unstable femoral trochanteric fracture model was created with fixation by cephalomedullary nails in 22 imitation bones. The 2 reduction patterns were as follows: one was with the proximal head-neck fragment external to the distal bone in the frontal plane and anterior in the sagittal plane as "Extramedullary," while the other was the opposite reduction position, that is, bone in the frontal plane and sagittal plane as "Intramedullary." We evaluated the tip-apex distance, compression stiffness, change in femoral neck-shaft angle, amount of blade telescoping, and diameter of the distal screw hole after the compression test. Statistical analysis was conducted using the Mann-Whitney U test. **Results:** No significant differences were seen in compression stiffness ($p = 0.804$) and femoral neck-shaft angle change ($p = 0.644$). Although the "Extramedullary" tip-apex distance was larger than the "Intramedullary" distance ($p = 0.001$), it indicated clinically acceptable lengths. The amount of blade telescoping and the distal screw hole diameter were significantly larger in "Intramedullary" than in "Extramedullary" ($p < 0.001$, $p = 0.019$, respectively). Our results showed that "Intramedullary" had significantly larger blade telescoping and distal screw hole diameters than "Extramedullary," and contrary to our hypothesis, no significant differences were seen in compression stiffness and femoral neck-shaft angle change. **Conclusions:** As opposed to the "Intramedullary" reduction pattern, the biomechanical properties of the "Extramedullary" reduction pattern improved stability during testing and decreased sliding.

Keywords

femoral trochanteric fracture, cephalomedullary nailing, fracture reduction

Introduction

Femoral trochanteric fractures often occur in elderly people owing to osteoporosis. In such instances, immediate surgery is required to improve their quality of life and decrease the mortality rate after injury.[1] Two types of implants can be utilized during surgery, i.e., cephalomedullary nails and sliding hip screws. Given that cephalomedullary nailing is associated with a lower risk of postoperative complications,[2-4] this technique is often preferred by surgeons when performing fixations. However, the overall failure rate of fixation operations for unstable femoral trochanteric fractures is 3-12%.[5-7]

Postoperative complications include blade/screw cutout, excessive blade/screw sliding, and broken implants.[8] Excessive blade/screw telescoping and varus collapse, which might have caused implant failure, occurred in unstable femoral

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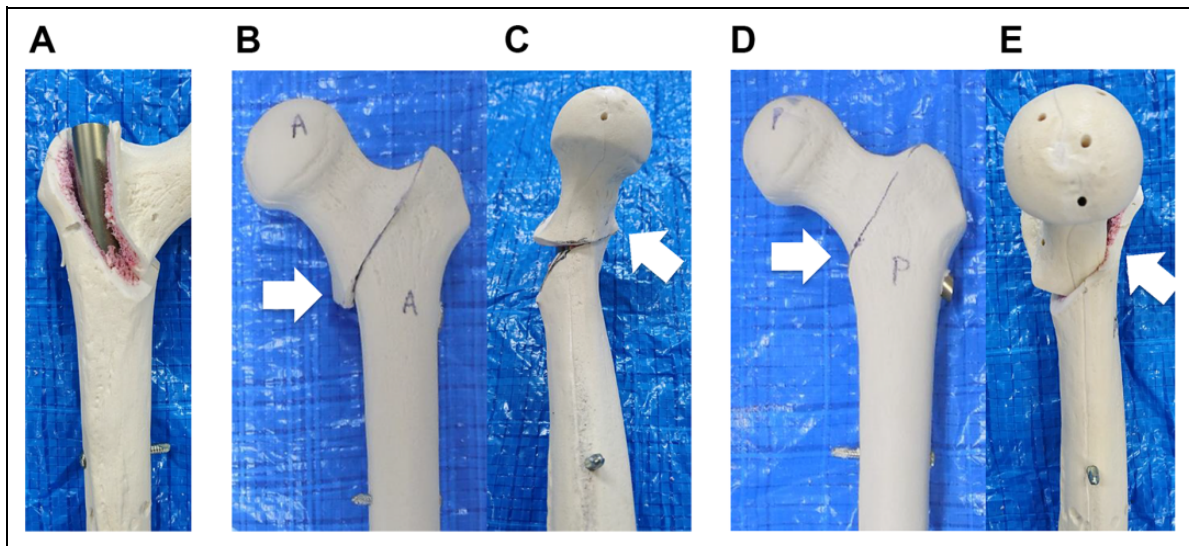Email: gontaasuke318@yahoo.co.jp

Figure 1. Reduction patterns for unstable femoral trochanteric fractures. Both types had a large posterior defect including greater and lesser trochanters (A). "Extramedullary" pattern (B and C) and "Intramedullary" pattern (D and E).

trochanteric fractures,[7,9] and the combination of critical factors, including incorrect reduction, non-optimal blade/screw position, and characteristic fracture pattern, could lead to blade/screw cut-out.[10] Among these critical factors, we can only control the reduction position and the blade/screw position. Therefore, fracture reduction and placement of the implant are crucial for a successful surgery. A previous study suggested that when the fragment was reduced and fixed by placing the medial cortex of the head-neck fragment slightly medial to the medial cortex of the femur shaft in AP view ("Extramedullary" reduction), the mechanical environment for fracture healing was better than that when the head-neck fragmented was fixed laterally to the upper medial edge of the femur shaft ("Intramedullary" reduction).[11] In addition, the anterior femoral neck cortex posterior to the distal fragment in the lateral view shows a higher risk of excessive sliding of the lag screws than does that located anterior to the distal fragment.[12,13] During the reduction procedure in the operating room, elevators and Kirschner wires are usually used as levers while the lesser trochanter represents the landmark. Briefly, a small incision is made above the lesser trochanter using fluoroscopy, which is followed by the insertion of the elevators into the fracture line to conduct reduction. However, no biomechanical evidence is available to support these clinical advantages.

Considering that these reduction patterns might have different biomechanical properties, we hypothesized that "Extramedullary" reduction is superior to "Intramedullary" reduction regarding the compression stiffness and the blocking capability of blade/screw sliding and implant movement inside the femur.

Materials and Methods

In this study, we created unstable femoral trochanteric fracture models and compared their mechanical stability based on the 2 different reduction patterns. We used imitation bone as an osteoporotic model (#1111, Sawbones; Pacific Research Laboratories, Vashon, WA, USA) to compare the 2 types of reduction patterns. Using an oscillating saw, we created the AO Foundation/Orthopedic Trauma Association (AO/OTA) classification 31A2.3 type unstable femoral trochanteric fracture models, with no support posteromedially and posterolaterally. The landmarks were the tip of the greater trochanter and the bottom of the lesser trochanter. While we first cut the imitation bone along the intertrochanteric crest using the bone saw, we then hollowed out the posterior wall fragment, so this fracture had a large defect posteriorly, including the greater and lesser trochanters (Figure 1A). We controlled variability by marking the same points and cutting at the same places on each bone with precision.

We placed the medial cortex of the proximal head-neck fragment "half of the cortex thickness" medial to the distal bone fragment in the frontal plane and anterior to the distal fragment in the sagittal plane as "Extramedullary" (Figure 1B, C).

We placed the medial cortex of the proximal head-neck fragment "half of the cortex thickness" inside the distal bone fragment in the frontal plane and posterior to the distal fragment in the sagittal plane as "Intramedullary" (Figure 1D, E).

We created 11 "Extramedullary" and 11 "Intramedullary" models, totaling 22 models.

We used an extra-short TFNA[TM] implant (DePuy Synthes, West Chester, PA, USA) with a 100-mm helical blade, a femoral neck angle of 130°, and a 5.0-mm distal locking screw for internal fixation in all 22 cases. The blade component in this implant was designed to slide within the nail for compression while maintaining the load-sharing characteristics at the fracture site. We positioned the entry point of the implant at the tip of the greater trochanter, placed the guide of the nail, reamed the femur, and inserted the interlocking nail into it. We then situated the guide of the helical blade toward the apex of the

femoral head and placed the helical blade while maintaining each reduction pattern, at the site where the penetration was confirmed to be safe by fluoroscopy. Finally, we placed one locking screw at the distal femur. After the operation, we measured the tip-apex distance (TAD)[14] as an indicator of the blade insertion position.

We performed a compression test on the prepared fracture models using an electromechanical universal testing machine (Instron model no. 33R4467; Instron Corporation, Norwood, MA, USA). The fractures of the models were reduced by both patterns to examine the mechanical stability of each and compared. Each specimen was fixed using a hand-made fixing stand to ensure the 20° adduction of the femur in the frontal plane. Adduction angles of 15°-25° have been shown to simulate the physiological loading of the proximal femur in the single-leg stance phase of the gait and have been used in other related biomechanical research studies.[15-17] We applied an axial pressure load at 10 mm/min from zero up to 2000 N. Load-displacement curves were collected and compression stiffness was calculated for each femur as the slope of the load-displacement curve. We also measured the change in the femoral neck-shaft angle, amount of blade telescoping, and distal screw hole diameter as indicators of nail motion in the femur and compared the parameters between the 2 different reduction patterns.

The Mann-Whitney U test was used for statistical analysis and the threshold for significance was $p < 0.05$. All statistical analyses were performed using SPSS software (version 19.0; SPSS, Chicago, IL, USA).

Results

We found that "Extramedullary" (17.5 $\pm$ 1.5 mm, range = 8.0-24.2 mm) showed larger TAD than did "Intramedullary" (10.1 $\pm$ 1.1 mm, range = 6.3-18.8 mm) ($p = 0.001$). There were no significant differences in compression stiffness ($p = 0.804$) and the change in the femoral neck-shaft angle ($p = 0.678$). The amount of blade telescoping after the compression test was significantly greater in "Intramedullary" (3.2 $\pm$ 0.4 mm, range = 2.0-6.9 mm) than in "Extramedullary" (0.19 $\pm$ 0.14 mm, range = -0.76-0.82 mm) ($p < 0.001$). In all "Intramedullary" specimens, the proximal head-neck fragment slid to the lateral side after the compression test (Figure 2). The distal screw hole diameter was also significantly larger in "Intramedullary" (6.7 $\pm$ 0.4 mm, range = 4.7-8.0 mm) than in "Extramedullary" (5.2 $\pm$ 0.19 mm, range = 4.7-6.4 mm) ($p = 0.019$). "Intramedullary" models showed enlargement of the distal screw hole after the compression test. (Table 1).

Discussion

This study showed that "Extramedullary" had significantly lower blade telescoping and distal screw hole diameter than "Intramedullary" after the compression test. To our knowledge, this is the first study to examine and compare biomechanical
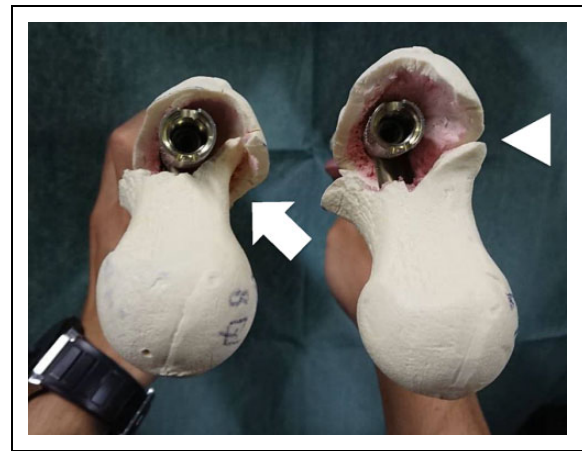

Figure 2. Movement of proximal head-neck fragment after compression testing for the 2 different reduction patterns in unstable femoral trochanteric fracture. "Intramedullary" pattern showed neck shortening without anterior bone contact (white arrow), while "Extramedullary" pattern showed anterior bone contact without neck shortening (white arrowhead).

properties of 2 different reduction patterns for the treatment of unstable femoral trochanteric fractures.

In the case of AO/OTA classification 31A2.3 type fracture, the fracture line in the anterior aspect of the trochanter occurs simply because the anterior component of the trochanter has a thick and strong bone cortex, while the fracture line in the posterior aspect collapses owing to the cancellous bone in the posterior component of the trochanter.[18] The thickness and bone quality of the anteromedial bone cortex are maintained even in elderly patients because the loading force while walking is transmitted through the anteromedial bone cortex of the proximal bone fragment.[19] Therefore, contact with the anterior medial cortex between the proximal head-neck fragment and distal fragment alone can support the loading force except in an implant in an unstable femoral trochanteric fracture. This is also an important factor in terms of load tolerance.

If effective bone-on-bone impaction is not applied, however, excessive sliding can occur. A previous study reported that excessive blade/screw telescoping often occurred[7] and caused postoperative complications such as blade/screw cutout and pseudoarthrosis in unstable femoral trochanteric fractures.[9] Excessive sliding indicates that the intended compression was not obtained and has been shown to predict clinical failure of the surgery.[20-22] In our study, the proximal head-neck fragment sliding increased with the loading force and did not stop until the proximal head-neck fragment reached the nail in "Intramedullary"; however, bone support was obtained early in the anterior medial cortex in "Extramedullary" (Figure 2). These findings indicated that when an excessive load was applied, the proximal head-neck fragment moved to the lateral side easily, and excessive telescoping occurred because there was no bone support of the anteromedial cortex in the "Intramedullary" pattern. In the results of our study, the amount of blade telescoping after the compression test was

Table 1. Results of the Biomechanical Test Series for 2 Different Reduction Patterns (Mean $\pm$ SE).

Variables	Extramedullary with subtype A (n = 11)	Intramedullary with subtype P (n = 11)	p value
Tip-apex distance (mm)	17.5 $\pm$ 1.5	10.1 $\pm$ 1.1	**0.001**
Compression stiffness (N)	212 $\pm$ 8.6	214 $\pm$ 6.9	0.804
Change in femoral neck-shaft angle (degrees)	7.9 $\pm$ 0.73	7.4 $\pm$ 0.84	0.678
Blade telescoping (mm)	0.19 $\pm$ 0.14	3.2 $\pm$ 0.41	**< 0.001**
Diameter of the distal screw hole (mm)	5.2 $\pm$ 0.19	6.7 $\pm$ 0.37	**0.019**

Mann-Whitney U test.
Bold values signifies p < 0.05.

found to be significantly greater in "Intramedullary" than in "Extramedullary"; this finding was in accordance with that of previous clinical reports, which showed Intramedullary pattern with excessive blade telescoping.[12,13]

Pervez et al. reported that the varus reduction position increased the risk of blade cutout.[23] In our experiment, although no significant differences were seen in the neck-shaft angle change, the distal screw hole diameter was larger in "Intramedullary" than in "Extramedullary." Enlargement of the distal screw hole indicated that the nail varus movement occurred in the femur during axial compression. In the "Extramedullary" pattern, the nail-bone construct consisted of 3 parts: the proximal head-neck fragment, intramedullary nail, and distal fragment. In contrast, the "Intramedullary" pattern showed that the nail-bone construct consisted of these 3 factors separately following 2 parts, proximal head-neck fragment-cephalomedullary nail and cephalomedullary nail-distal fragment, owing to the absence of bony contact in the anteromedial area between the proximal head-neck fragment and distal bone. In this condition, the axial compression load was concentrated on the distal screw through the head-neck fragment to the cephalomedullary nail; the nail varus movement occurred in the femur in the "Intramedullary" pattern under a high loading force. To prevent the concentration of stress at the site of the distal screw, which might cause nail varus movement in the femur, the anterior medial bone contact was essential to share the loading force in unstable femoral trochanteric fractures.

The location of the implant after the operation also affected the frequency of implant failure. Baumgaertner et al. mentioned that the TAD played an important role in preventing implant failure.[14,24] Brujin et al. reported that TAD > 25 mm was related to the risk of screw cutout.[25] As shown by our results, TAD in "Extramedullary" and "Intramedullary" reductions did not exceed the recommended standard value of 20 mm.[26] Although TAD in "Intramedullary" was significantly lower than that in "Extramedullary," "Intramedullary" showed a significantly greater amount of blade telescoping and distal screw hole diameter than did "Extramedullary." Thus, the "Extramedullary" reduction pattern was preferable in unstable femoral trochanteric fractures.

There were a few limitations to this study. First, we used imitation osteoporotic bone model material that might not have replicated the biomechanical properties of human bone exactly. However, synthetic bone is easy to handle without interspecies variability, indicating that the differences among the groups were due to the reduction pattern itself. Second, we could not consider the condition of the soft tissue, including muscles and ligaments, which may affect the reduction pattern. Third, we evaluated just 2-dimensional displacements; we could not assess the rotation of the proximal fragment. Fourth, only axial loading force could be reproduced; the stress on the hip joint during walking, which might be measured using the cyclic-load test, was not reproducible. However, we showed that "Intramedullary" reduction was less stable than was "Extramedullary" reduction in the femur even by a single axial compression load. We believe that our biomechanical results support previous clinical studies.[12,13] Further experiments, such as 3D evaluation and fatigue testing using cadaveric bone should be conducted to explore the differences in the biomechanical properties between the 2 reduction patterns.

Conclusions

The "Extramedullary" reduction pattern provides anterior medial bone support and is biomechanically superior to the "Intramedullary" reduction pattern. Anterior medial bone contact is necessary for the treatment of unstable trochanteric femoral fracture to avoid postoperative complications following excessive telescoping or varus collapse. There is a scope for future studies on human models to verify our findings.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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