


# Biomechanical Comparisons of Trochanteric Hip Fracture Fixation Using Short-, Mid-, and Long-Length Proximal Femoral Nails

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## Abstract

**Introduction:** For trochanteric hip fractures, proximal femoral nails (PFNs) have been frequently used for surgical treatment. No study has clarified whether length of the nail affected the wiper motion; the repetitive motion of the distal nail inside canal after surgery. **Methods:** Thirty synthetic femora were used to biomechanically evaluate construct lateral angular movement of 3 different lengths of PFN [TFN-ADVANCED Proximal Femoral Nailing System (TFNA) 170 (short-length), 235 (mid-length), and 300 (long-length) mm] constructs for the fixation of stable pertrochanteric fractures. Cyclic testing and radiological evaluation were performed to investigate the loosening patterns in 3 different fixation constructs. Migration along the mechanical axis during the cyclic testing from 1-100<sup>th</sup>, 100-500<sup>th</sup>, 500-1000<sup>th</sup>, 1000-1500<sup>th</sup>, and 1500-2000<sup>th</sup> cycles was compared between TFNA lengths. Also, before and after cycling changes in tip to apex distance, angulation of fracture line, and lateral angular movement of the distal stem inside the canal were compared between TFNA lengths. **Results:** Migration along the mechanical axis during cyclic loading, plus changes after cycling in tip to apex distance, and fracture line angulation did not differ between TFNA lengths for the fixation of stable intertrochanteric fracture model using synthetic femora. Conversely, one-way analysis of variance revealed a significant difference in lateral angular movement of the distal stem inside the canal after cyclic testing between groups ( $1.4 \pm 1.6^\circ$ ,  $.21 \pm .35^\circ$ , and  $.26 \pm .57^\circ$  in 170-mm short nail, 235-mm middle nail, and 300-mm long nail, respectively;  $P = .026$ ), and post-hoc analysis also revealed that middle nail yielded significantly less lateral angular movement compared with short nail ( $P = .047$ ) but did not significantly differ from the long nail. **Conclusions:** Mid-length TFNA for the fixation of stable trochanteric hip fracture model using synthetic femora resulted in significantly smaller lateral angular movement of the distal stem after cyclic loading.

## Keywords

trochanteric hip fracture, proximal femoral nail, the TFN-ADVANCED proximal femoral nailing system, mid-length nail, biomechanical study

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## Introduction

The frequency of hip fractures has been continuously increasing with the aging of populations in various countries worldwide.<sup>1,2</sup> For trochanteric hip fractures, proximal femoral nails (PFNs) have been frequently used for surgical treatment. Although several studies have reported which implant yields a better clinical outcome, there is currently a paucity of good supporting biomechanical evidence for this question.

The TFN-ADVANCED Proximal Femoral Nailing System (TFNA) 235 mm (DePuySynthes, Zuchwil, Switzerland) was developed to achieve better stability for patients with trochanteric hip fractures without increasing the surgical time and blood loss. Its morphological features include the nail of 35 mm longer than 200 mm a short nail and the distal locking screw hole at the same location so that the same surgical instrument for the shorter nail can be used to facilitate the surgical procedure, which aims to obtain better stress distribution around the nail. Matsumura et al. had retrospectively evaluated a Japanese patient cohort of >70-year-olds with trochanteric hip fractures who underwent internal fixation using the TFNA 235 mm and PFNA-II 240 mm.<sup>3</sup> In that study, they first clarified that all nails of the TFNA 235 mm and PFNA-II 240 mm were successfully inserted below the end of the isthmus not only without jamming but also without additional reaming to dilate the canal. Second, internal fixation using these 2 implants with trochanteric hip fractures resulted in favorable outcomes with acceptable surgical time and amount of blood loss. Third, the union rate was good, the complication rate was acceptable, and no adverse effects due to the longer nail<sup>4</sup> occurred. From these results, the strength of 235-mm mid-length PFNs was speculated to decrease the wiper motion, which Matsumura et al defined as repetitive motion of the distal nail inside the femoral canal,<sup>3</sup> compared with the 170-mm short-length nails without nail jamming. This phenomenon was occasionally observed when shorter nails were used, especially in cases with a stovepipe-type femur.<sup>3</sup> Ceynowa et al described that the intramedullary devices are prone to early dislocation in patients with a large medullary canal fixed with a nail relatively smaller in diameter.<sup>5</sup> Therefore, the wiper motion can cause lateral angular movement after the fracture reduction, because early deterioration of the fixation might be caused by the repetitive motion of the distal nail inside the femoral canal.

However, in our recent literature search, no biomechanical studies have currently clarified this speculation. Therefore, we hypothesized that 235-mm mid-length PFNs can decrease the wiper motion during the cyclic testing, thus resulting in less postoperative reduction loss after the cyclic testing compared with the 170-mm short-length nail. Another hypothesis is that wiper motion during and

postoperative reduction loss after the cyclic testing is comparable with the long-length nail. Therefore, this biomechanical study aimed to clarify these hypotheses.

## Material and Methods

### *Nail Implantation and Fracture Simulation*

Clinical Research Ethics Committee of our institute waived the ethical approval because this biomechanical study used synthetic bone and PFN. Thirty synthetic femora (Sawbones Worldwide, Vashon, WA) were used to biomechanically evaluate construct lateral angular movements of 3 different lengths of PFN (TFNA 170, 235, and 300 mm) constructs for the fixation of per-trochanteric fractures.<sup>6</sup> Study procedures were based on those demonstrated in a previous study conducted by Marmor et al.<sup>6</sup> We could not obtain a similar synthetic femur model to Marmor's study (polyurethane made)<sup>6</sup> because of no distribution in our country. Therefore, we alternatively utilized a different model (Femur, Foam Cortical, Left, Medium SKU:1121; Sawbones Worldwide, Vashon, WA), which was made from a softer material than the Marmor's polyurethane model. The inner cancellous material of the Sawbones femora were reamed using a 15-mm diameter drill. The procedure was performed as a surrogate preparation for stovepipe femur. Femora were randomly assigned to 3 groups (10 per group) implanted with one of the following: TFNA 170, 235, and 300 mm. All implants were inserted into the femora by 1 senior trauma surgeon (T.M.) based on the official surgical instruction. All constructs consisted of a 9-mm-distal-diameter nail with a 125° neck angle and a 90-mm-length lag screw. A 36-mm locking screw was inserted in the central midshaft static locking hole. A stable per-trochanteric fracture model (AO/OTA 31A1.2) was created for each of the implanted femora using a surgical oscillating saw (Figure 1). An oblique osteotomy was created from the central lateral aspect of the greater trochanter to the pinnacle of the lesser trochanter.

### *Biomechanical Evaluation*

Cyclic testing was performed to investigate the loosening patterns in 3 different fixation constructs. The prepared constructs were mounted on a tensile tester (Tensilon RTG 1310, Orientec Co. Ltd., Tokyo, Japan) with a set of specially designed grips (Figure 2). Each femur was oriented; therefore, cyclic loading was applied along the mechanical axis of the femur. After cutting off 10 cm of the distal femur, the distal 4 cm of each femur was clamped using a custom-made jig. A load-displacement curve was created using specific software (Tensilon Advanced



**Figure 1.** A stable trochanteric fracture model (AO/OTA 31A1.2) was fixed using TFN-ADVANCED Proximal Femoral Nailing System.

Controller for Testing, Orientec Co., Ltd., Japan) (Figure 3). Then, the femora were cyclically loaded up to 500 N (2000 cycles, .5 Hz). A previous study conducted by Singh et al<sup>7</sup> demonstrated to stimulate a young adult 70 kg bodyweight and loaded cyclically at 2000 N. In our preliminary experiments, a 2000 N cyclic load resulted in the breaking of a synthetic femur model. Therefore, we chose a 500 N cyclic load with an estimation for the partial weight-bearing of an older person with a bodyweight of 50 kg. Migration along the mechanical axis from 1-100<sup>th</sup>, 100-500<sup>th</sup>, 500-1000<sup>th</sup>, 1000-1500<sup>th</sup>, and 1500-2000<sup>th</sup> cycles were determined through software calculations of actuator displacements during cycling.

### Radiological Evaluation

Anterior and posterior X-ray of all femurs was taken, and changes in tip to apex distance, angulation of fracture line before and after cyclic testing, and lateral angular movement of the distal stem inside the canal after cyclic testing

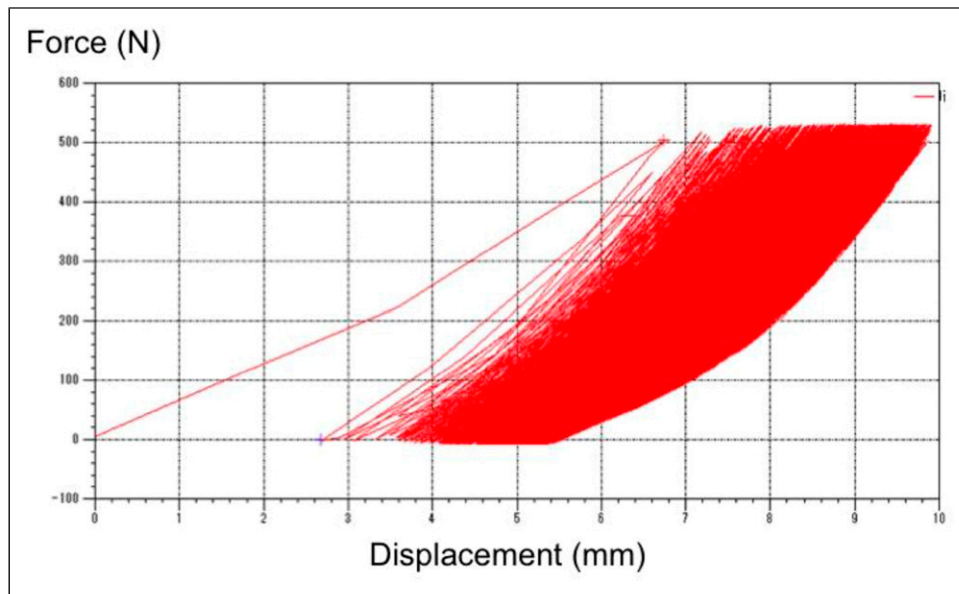


**Figure 2.** Tensile tester with a set of specially designed grips to hold the distal femur.

(Figure 4). were evaluated using the Picture Archiving and Communicating System monitor (GE Healthcare, Barrington, IL, USA).<sup>8</sup>

### Statistical Analyses

A one-way analysis of variance (ANOVA) among 3 groups with Bonferroni post-hoc analysis was used to evaluate between-group differences. All data are presented as mean  $\pm$  standard deviations. *P*-values of  $<.05$  were considered statistically significant. A priori power analysis was performed using G\* Power 3.1 (Franz Paul, Kiel, Germany).<sup>9</sup> All statistical analyses were performed using EZR software.<sup>10</sup>



**Figure 3.** Schematic image of the load-displacement curve generated during cyclic testing.

## Results

### Displacement During Cyclic Loading

No significant differences were observed in migration along the mechanical axis for the 1-100<sup>th</sup> ( $.60 \pm .20$ ,  $.76 \pm .15$ , and  $.74 \pm .16$  mm in 170-mm short nail, 235-mm middle nail, and 300-mm long nail, respectively), 100-500<sup>th</sup> ( $.56 \pm .36$ ,  $.69 \pm .27$ , and  $.50 \pm .19$  mm in 170-mm short nail, 235-mm middle nail, and 300-mm long nail, respectively), 500-1000<sup>th</sup> ( $.23 \pm .088$ ,  $.38 \pm .25$ , and  $.30 \pm .11$  mm in 170-mm short nail, 235-mm middle nail, and 300-mm long nail, respectively), 1000-1500<sup>th</sup> ( $.15 \pm .077$ ,  $.43 \pm .62$ , and  $.15 \pm .069$  mm in 170-mm short nail, 235-mm middle nail, and 300-mm long nail, respectively), and 1500-2000<sup>th</sup> cycles ( $.12 \pm .051$ ,  $.33 \pm .44$ , and  $.14 \pm .054$  mm in 170-mm short nail, 235-mm middle nail, and 300-mm long nail, respectively) (Figure 5).

### Radiological Evaluation

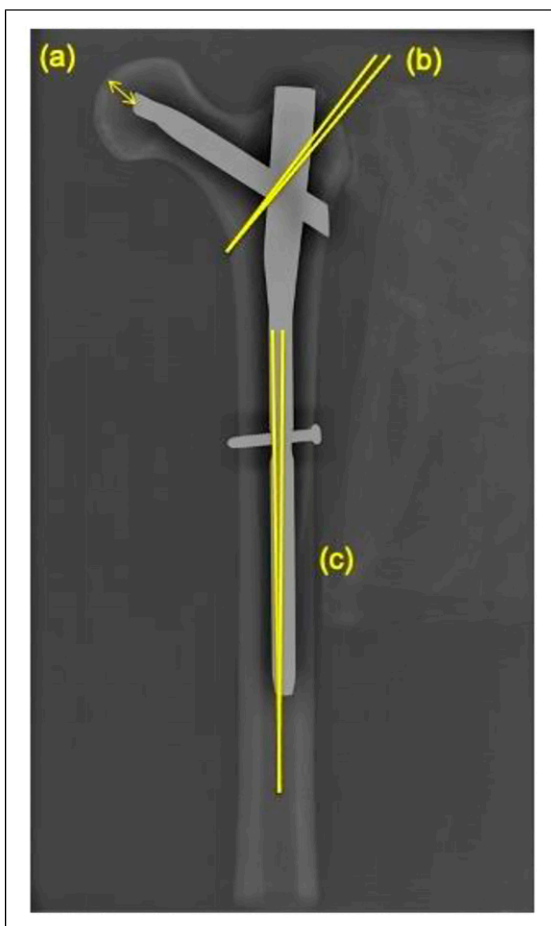
No significant differences were observed in a change in tip to apex distance ( $.50 \pm 1.1$ ,  $.64 \pm .89$ , and  $.50 \pm 1.1$  mm in 170-mm short nail, 235-mm middle nail, and 300-mm long nail, respectively) and angulation of the fracture line ( $1.1 \pm 1.7^\circ$ ,  $.37 \pm 1.3^\circ$ , and  $.067 \pm 1.7^\circ$  in 170-mm short nail, 235-mm middle nail, 300-mm long nail, respectively) before and after cyclic testing. On the contrary, one-way ANOVA revealed a significant difference in lateral angular movement of the distal stem inside the canal after cyclic testing between groups ( $1.4 \pm 1.6^\circ$ ,  $.21 \pm .35^\circ$ , and  $.26 \pm .57^\circ$  in 170-mm short nail, 235-mm middle nail, and 300-mm long

nail, respectively;  $P = .026$ ), and post-hoc analysis also revealed that middle nail yielded significantly less lateral angular movement compared with short nail ( $P = .047$ ) but did not significantly differ from the long nail (Figure 6).

## Discussion

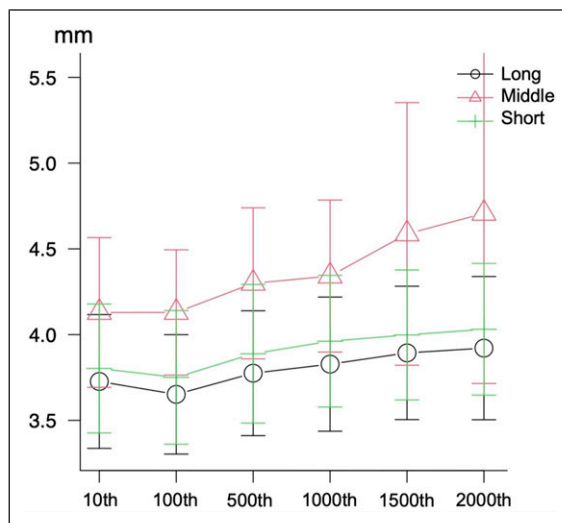
In the current study, the biomechanical properties of short-, mid-, and long-length TFNA for stable pertrochanteric fractures were investigated using biomechanical cyclic loading tests. We clarified that migration along the mechanical axis during cyclic loading, plus changes after cycling in tip to apex distance, and fracture line angulation did not differ between short-, mid-, and long-length TFNAs for the fixation of stable intertrochanteric fracture model using synthetic femora. Conversely, the averaged lateral angular movement of the distal stem in the mid-length TFNA inside the canal after cyclic loading was significantly smaller than that of short-length TFNA but did not significantly differ from that long-length TFNA. The study supports the concept that the longer stem of mid-length TFNA is critical in maintaining the stem position while treating pertrochanteric fractures and allowing early weight-bearing. Matsumura et al described that mid-length PFN exceeds the femoral isthmus in smaller-frame patients such as the Japanese elderly people.<sup>3</sup> This might decrease the wiper motion, a repetitive motion of the distal nail inside the femoral canal. This phenomenon was occasionally observed when shorter nails were used.<sup>3</sup> Decreased lateral angular movement of the distal stem in the mid-length TFNA inside the canal is based on their speculation.



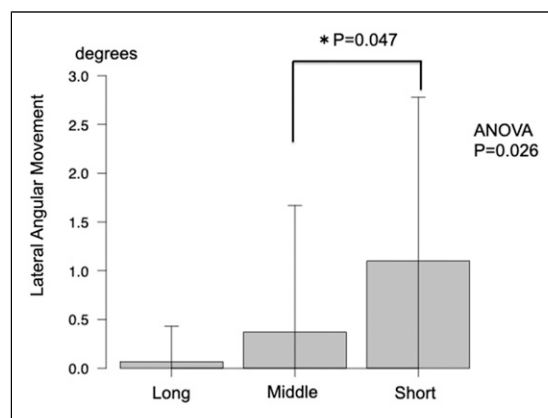


**Figure 4.** Anterior and posterior X-ray of the specimen was taken, before and after cycling indicating (A) changes in tip to apex distance, (B) angulation of fracture line before and after cyclic testing, and (C) lateral angular movement of the distal stem inside the canal after cyclic testing.

Currently, a cephalomedullary nail is generally used as the most reliable implant for inter- or pertrochanteric femoral fractures, and favorable clinical outcomes can be acquired. Since there is no current consensus on which implant length is the optimal choice for these fractures, the choice of a nail length is based on the surgeon's preference. Although an orthopedic surgeon tends to use the longer nail especially for unstable trochanteric fractures such as AO/OTA 31A2 and A3 because they appear to prevent loss of reduction, secondary periprosthetic fractures, and thigh pain, no clinically significant differences were observed between short and long nails in recent reports.<sup>11,12</sup> Moreover, from a biomechanical perspective, the risk of secondary periprosthetic fractures after intramedullary fixation of pertrochanteric fractures is similar when using short or long nails.<sup>13</sup>



**Figure 5.** Results of migration along the mechanical axis among short, mid, and long TFN-ADVANCED Proximal Femoral Nailing System.



**Figure 6.** Results of lateral angular movement of the distal stem inside the canal after cyclic testing among short, mid, and long TFN-ADVANCED Proximal Femoral Nailing System.

Postoperative cut out of the lag screw was the unsolved problem, and the occurrence was reported to be 1.0 to 6.9% in the meta-analysis.<sup>14</sup> No significant differences concerning changes in tip to apex distance of the lag screw and angulation of the fracture line after cyclic loading were observed among groups. One of the plausible reasons was we created a stable fracture model in this study, and thus, whether significant differences will be observed between these implants is our future study when used in an unstable trochanteric hip fracture model. However, it is a significant proof that the wiper motion can be minimized by a usage of the mid-length TFNA, nevertheless the simple biomechanical model which doesn't allow movements along the

3 axes of freedom was adopted and the difference between the medial canal and the diameter of a stem was only 6 mm.

## Limitations

Our study has several limitations. First, we didn't use human cadaveric femur; instead, synthetic femora were used in this study that might affect the results. However, the canals were reamed to 15 mm to be a surrogate for stovepipe femur. Second, the fracture was artificially created using an oscillating saw to establish a smooth surface. This condition was not similar to actual clinical settings. Conversely, in vivo fractures tend to produce a rawer irregular surface. Third, loads at the hip joint during activities of daily living range from 50% to 350% bodyweight.<sup>15,16</sup> We set the loads used in cyclic loading at 500 N to clarify the effects of the stem length on not maximum failure load or stiffness; however, maintaining the implant position after repetitive stresses was similar to that in daily activities. Fourth, the number of cyclic loadings was set at 2000 cycles. Patients after a total hip or knee replacement were reported to walk averaged 5000 steps per day.<sup>17</sup> In that study, age was a significant factor for increased steps, with patients aged <60 years walking 30% more on average than those aged ≥60 years. The average steps were reported to be approximately 5000-7000 steps per day; however, patients recovering from trochanteric hip fractures may alter their weight-bearing routine, and a sedentary person was found to walk approximately 1000-3000 steps per day. Therefore, we set the number of cyclic loading to 2000 cycles.

However, despite several acknowledged limitations, to the best of our knowledge, this is the first study to investigate the biomechanical advantages of mid-length TFNA when compared with those of short-length TFNA for trochanteric hip fractures using cyclic loading conditions. This study has demonstrated the potential advantage of reduced wiper motion when using a mid-length nail instead of a short-length nail.

## Conclusion

Mid-length TFNA for the fixation of trochanteric hip fracture model using synthetic femora resulted in significantly smaller lateral angular movement of the distal stem after cyclic loading. When treating trochanteric hip fractures, the use of mid-length TFNA is worth considering because the wiper motion causing reduction loss can be minimized moreover, the distal locking screw hole is located similarly, so that the same surgical instrument for the short-length TFNA can be used to facilitate the surgical procedure.

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