

Original Article

A biomechanical comparison of proximal femoral nails and locking proximal anatomic femoral plates in femoral fracture fixation

A study on synthetic bones

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ABSTRACT

Background: The incidence of fractures in the trochanteric area has risen with the increasing numbers of elderly people with osteoporosis. Although dynamic hip screw fixation is the gold standard for the treatment of stable intertrochanteric femur fractures, treatment of unstable intertrochanteric femur fractures still remains controversial. Intramedullary devices such as Gamma nail or proximal femoral nail and proximal anatomic femur plates are in use for the treatment of intertrochanteric femur fractures. There are still many investigations to find the optimal implant to treat these fractures with minimum complications. For this reason, we aimed to perform a biomechanical comparison of the proximal femoral nail and the locking proximal anatomic femoral plate in the treatment of unstable intertrochanteric fractures.

Materials and Methods: Twenty synthetic, third generation human femur models, obtained for this purpose, were divided into two groups of 10 bones each. Femurs were provided as a standard representation of AO/Orthopedic Trauma Association type 31-A2 unstable fractures. Two types of implantations were inserted: the proximal femoral intramedullary nail in the first group and the locking anatomic femoral plate in the second group. Axial load was applied to the fracture models through the femoral head using a material testing machine, and the biomechanical properties of the implant types were compared.

Result: Nail and plate models were locked distally at the same level. Axial steady load with a 5 mm/m velocity was applied through the mechanical axis of femur bone models. Axial loading in the proximal femoral intramedullary nail group was 1.78-fold greater compared to the plate group. All bones that had the plate applied were fractured in the portion containing the distal locking screw.

Conclusion: The proximal femoral intramedullary nail provides more stability and allows for earlier weight bearing than the locking plate when used for the treatment of unstable intertrochanteric fractures of the femur. Clinicians should be cautious for early weight bearing with locking plate for unstable intertrochanteric femur fractures.

Key words: Biomechanical comparison, intertrochanteric femur fractures, intramedullary nail, proximal anatomic femoral plate

MeSH terms: Femur, femoral neck fractures, fracture fixation, intramedullary

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INTRODUCTION

Hip fractures can lead to severe morbidity and mortality, especially in older adults.¹ Allowing patients to get out of bed earlier and promoting early mobilization is necessary to prevent complications such as deep vein thrombosis, bedsores, pulmonary infection, and muscle atrophy. In elderly patients, early mobilization without weight bearing may not be clinically possible. Therefore, stability of the preferred fixation method is crucial.

Unstable intertrochanteric fractures are difficult to treat and the treatment method still remains controversial. Intramedullary nailing is usually the preferred surgical method for fixation.²⁻⁴ When the proximal femoral

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	DOI: 10.4103/0019-5413.156220

intramedullary nail is inserted, the lever arm loading on the implant around the hip shortens due to transmission of the load medially, and bending forces can be resisted more successfully due to the rigidity of the nail.⁵ However, further research into other implants remains necessary due to the prevalence of complications including excessive femoral bowing, varus malposition (encountered during intramedullary nail insertion and the “cut-out” of the sliding-hip-screw), as well as the “Z-effect” and implant failure.⁶

The locking proximal anatomic femoral plate is part of a new generation of plates developed in an effort to increase early mobilization of patients. They are theoretically superior to intramedullary nails because they can be applied with less bone injury and provide stabilization through the placement of more screws at different angles into the proximal portion of the femur.⁷ In prior biomechanical studies, locking proximal anatomic femoral plates were found to be superior to other plate designs in the treatment of proximal femoral fractures.⁸⁻¹⁰ The aim of our study was to perform a biomechanical comparison of the intramedullary nail and the locking proximal anatomic femoral plate in the treatment of the unstable intertrochanteric femoral fractures using synthetic bone fracture models.

MATERIALS AND METHODS

20 third generation femur models (Synbone, no: 2221, Switzerland) were provided as a standard representation of AO/Orthopedic Trauma Association type 31/A2 unstable fractures. The characteristics of the bone models used were as follows: Length: 337 mm, neck angle: 135°, anteversion: 15°, head diameter: 48 mm and canal diameter: 10mm. Femoral bone models were divided into two groups, each comprised of ten bones. Fixation was performed on the femoral bone models in both groups by a single surgeon.

A Titanium-locking proximal anatomical femoral plate with ten screw holes (TST SAN, Istanbul, Turkey) was placed on the bones in the first group [Figure 1]. The length of the plate was at least 3 times the length of the fracture line. While the fracture was in the reduced position, osteosynthesis was achieved by inserting eight screws from the implanted plate into the lateral aspect of the proximal femur in three regions of the femur as follows: Three spongy bone screws (6.5mm diameter) at different angles and one kickstand screw (4.5 mm cortical) to the femur head, one screw (4.5 mm cortical) to the trochanter minor and three screws (4.5 mm cortical) to the femoral shaft [Figure 2a and b].

A proximal femoral nail made up of titanium alloy (TST SAN, Istanbul, Turkey) was placed into the femur in the second group. The proximal diameter of the nail was 16 mm and the distal diameter was 10 mm. There was a slot at the distal end of the nail and the proximal angle was 6°. In addition, the nail had a neck-shaft angle of 135°. During the insertion of the intramedullary nail into the bone models, the proximal portion of the bone was enlarged using an appropriate-sized drill. The size of the nail was selected to be 10 × 220 mm using the distal diameter of the femur models. After insertion of the intramedullary nail, cannulated k-wires were placed into the femoral head using the guide of the system. The nail was adjusted to allow 15° of anteversion. Next, two proximal locking screws (8.5 mm dia) and one distal locking screw (3.5 mm dia) were inserted by means of a guide [Figure 2c and d].

Fixation of all bone models was performed by a single orthopedic surgeon. The Shimadzu Autograph AGS testing device was used to measure the compressive strength of the specimens [Figure 3]. The biomechanical loading test was performed by a single metallurgical and materials engineer under the supervision of the orthopedic

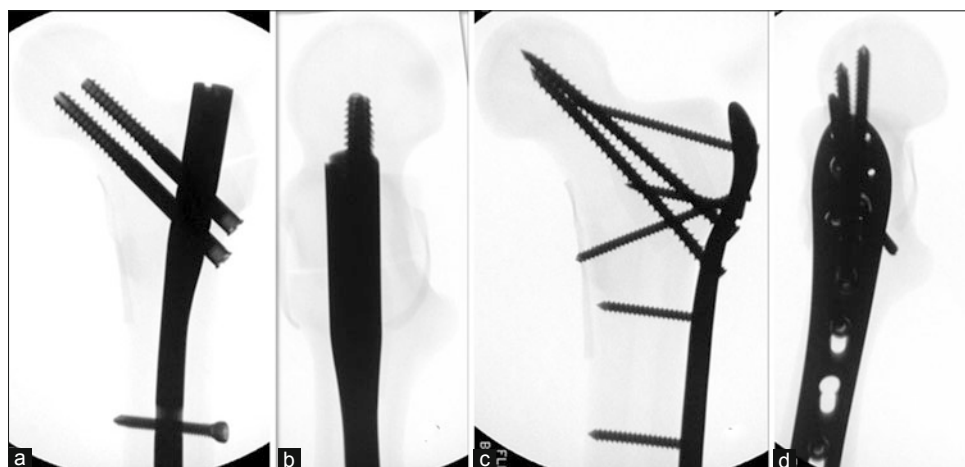


Figure 1: X-ray images of bone-implant construct models: (a and b) anteroposterior and lateral views of the intramedullary nail applied on fractured femur model. (c and d) Anteroposterior and lateral view of the plate applied on fractured femur model

surgeon. An axial force at a constant velocity of 5 mm/min was exerted onto the femoral head in accordance with the mechanical axis of the femur. The exertion of the axial force on the femoral heads was delivered in accordance with the mechanical axis of the femur. The distal portion of the femur was placed on a flat table. When the breaking strength of the specimen was reached the specimen was fractured and the value was recorded. Fractured regions of the bone models and the type of fractures were also recorded. For statistical analyses, Mann-Whitney U-test was used to compare the independent two groups

RESULTS

All ten bone models with femoral plates fractured just below the distal locking screw [Figure 4a]. All bone models with femoral plates fractured at an angle of $<30^\circ$. One of the bone models with a proximal femoral nail fractured at the proximal portion of the nail, two at both the proximal and distal portions of the nail and the remaining models fractured at the distal portion of the nail [Figure 4b].



Figure 2: Pictures of bone-implant construct models: (a and b) Anteroposterior and lateral view of the plate applied on fractured femur model. (c and d) Anteroposterior and lateral view of the intramedullary nail applied fractured femur model



Figure 3: Positioning of bone-implant construct and biomechanical loading test with Shimadzu Autograph AGS testing device

A displaced butterfly fragment occurred in three of the proximal femoral nail group bone models. There was a tendency for comminuted fractures at the distal portion in the bone models in the proximal femoral nail group [Figure 4c]. A displaced butterfly fragment did not occur; however, a nondisplaced butterfly fragment occurred in four of the proximal femoral nail bone models. An oblique fracture occurred with an angle $>30^\circ$ in all proximal femoral nail bone models, with fractures occurring in the distal portion of the bone.

The average force exerted at the time of the fracture was 1559.4 N in the proximal femoral nail group. The average force exerted at the time of fracture was 875.77 in the plate bone model group [Tables 1 and 2 and Figures 5 and 6]. Results were statistically analyzed, and results of two groups were found to be significantly different ($P < 0.005$). The bone models with the inserted proximal femoral nails were ~ 1.78 -fold stronger than bone models with a plate applied.

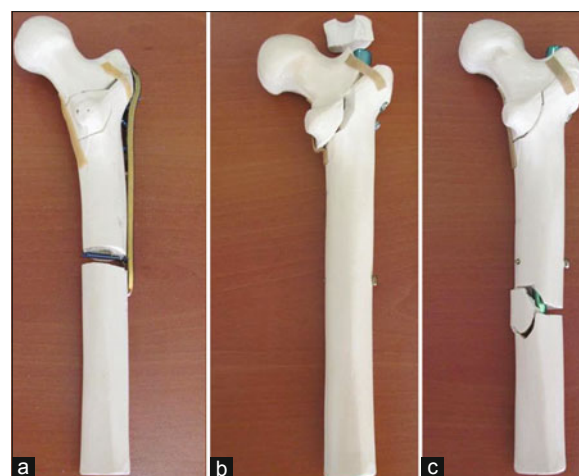


Figure 4: Fracture patterns for two groups after loading test. (a) Fracture occurred just below the plate in plate applied bone model. (b) Fracture occurred at the tip of the nail in the intramedullary nail applied bone model. (c) Displaced butterfly fragment occurred distally in the intramedullary nail applied bone model

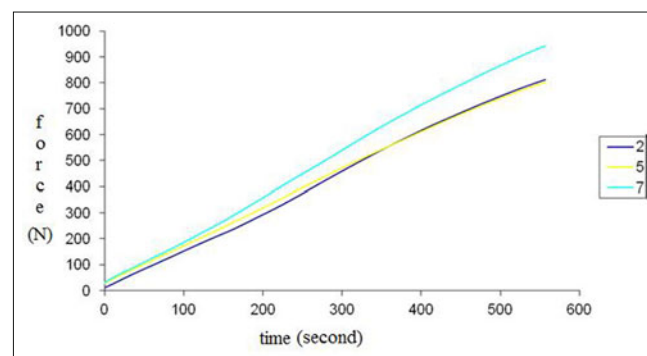


Figure 5: Force-time curves for the bone models numbered 2-5-7 with plates applied

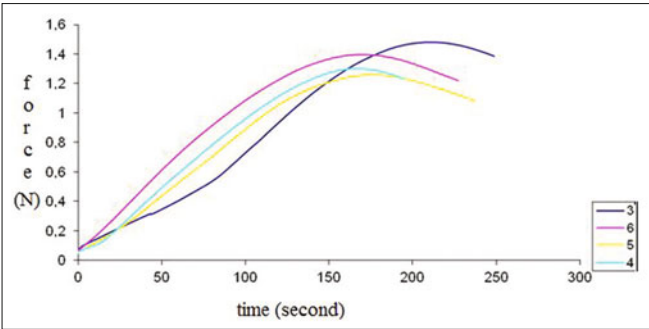


Figure 6: Force-time curves for the proximal femoral nail bone models numbered 3-4-5-6

Table 1: Compression results of the bone models with a plate applied

Specimen number	Compressive strength (at the time of fracture) (newton)	Compressive strength (at the time of fracture) (Kgf)
1	806.40	80.64
2	930.35	93.03
3	925.25	92.53
4	833.95	83.40
5	876.20	87.62
6	797.00	79.70
7	997.05	99.71
8	875.00	87.50
9	910.80	91.08
10	805.70	80.57

Table 2: Compression results of the proximal femoral nail bone models

Specimen number	Compressive strength (at the time of fracture) (newton)	Compressive strength (at the time of fracture) (Kgf)
1	1501.5	150.15
2	1695.0	169.50
3	1480.0	148.00
4	1299.0	129.90
5	1259.5	125.95
6	1399.0	139.90
7	2010.0	201.00
8	1405.0	140.50
9	1695.0	169.50
10	1850.0	185.00

DISCUSSION

The incidence of intertrochanteric femoral fractures has been increasing in parallel with the gradually increasing human lifespan, and they are one of the most important causes of mortality and morbidity among this population.¹¹ Today, the standard treatment for these fractures usually involves internal fixation methods namely extramedullary or intramedullary implants. These methods aim to provide anatomical reduction of the

fracture through the use of an appropriate implant for the fracture type that fixes the bone in a stable position and allows for early mobilisation.¹²

In recent years, the use of proximal femoral locking compression plates (PF-LCP) for the treatment of fractures of the trochanteric region has become popular because insertion can be completed using minimally invasive techniques. These plates provide greater stability than other plates because they are locking and allow for the placement of screws at different angles.¹³ In our study, a biomechanical comparison of the locking proximal anatomic femoral plate and the proximal femoral intramedullary nail was performed to determine the ideal implant for use in the unstable intertrochanteric fracture model. The synthetic bone models used were third-generation femur models with properties similar to natural human bone.

In our review of the literature, we discovered that in prior biomechanical studies when plate application was tested in subtrochanteric fracture models, varus collapse, or implant failure occurred as a consequence of the lack of medial support.^{8,9,14}

A kickstand screw was used to prevent the complication of varus collapse, encountered after the insertion of PF-LCP plates.⁸ Hence, a kickstand screw to prevent this complication in the plates was also used in our fracture models. Varus collapse or implant failure was not observed in any of the bone models with PF-LCPs. However, all of the bone models with femoral plates were fractured transversely from the portion where the distal locking screw was present. We believe that this complication occurred as a consequence of the transmission of the stress to the area of the distal locking screw.

Implant failure, among other complications reported for intramedullary nail insertions, was commonly attributed to poor reduction and improper implant placement.¹⁵ Besides, osteoporosis and lack of posteromedial support in unstable intertrochanteric fractures increased the rate of clinical failure.¹⁶ We had used two lag screws of the same diameter in our nails to enhance the stability and decrease the lag screw cut-out. Furthermore, insertion of inferior lag screw as close as to inferior femoral neck was done to have the strongest purchase of the screw as the compression and tension trabecular meet at that area. Furthermore, the lag screws were inserted upto 10 mm of subchondral bone to increase the stability. Fractures that occur in the distal portion of the nail were usually associated with implant geometry and shape and not related to the quality of reduction. We attempted to minimize the risk of the distal fracture through the use of a distally slotted nail. However, cortical fracture

occurred under a load of $\sim 1,600$ N even when the nail had a slot at the distal end. These tended to be comminuted fractures with greater inclination angles in comparison to the transverse fractures seen in the plate application models due to the less energy transmission ability of the plates.

In prior biomechanical studies of hip implants, intramedullary nails were demonstrated to be biomechanically superior to dynamic hip screw and angled blades.¹⁷ This superiority is thought to be a consequence of the efficient load transfer due to the closed proximity of the nail is in close proximity to the mechanical axis. Furthermore, there is a lower risk of mechanical failure due to load reduction on the implant due to the shorter lever arm and a controlled fracture impaction. The nail is intramedullary and medialization of the distal end is prevented, especially in reverse oblique fracture types.¹⁸ With intramedullary nail insertion, immediate postoperative weight bearing and mobilization are possible, particularly in elderly patients.^{17,19} We also observed in this study that intramedullary nails provided a stronger fixation than did anatomical locked plates.

According to our study, intramedullary nail fixation provides more stable fixation in the unstable intertrochanteric fracture model than locking proximal anatomic femoral plates. Early weight bearing in the patients with PF-LCP fixation should be allowed with caution.

The limitation of this study was that; although study reflects the biomechanical properties of plate and intramedullary fixation of unstable intertrochanteric femoral fractures, it should have been better if the failure test was done using cyclical loading which had been more similar to physiological loading of daily activities. The study is on synthetic bones and is not on cadaveric bones and live bones. The sample size is very small. Further clinical correlation with large multicentric randomized controlled studies are required.

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How to cite this article: Ozkan K, Türkmen I, Sahin A, Yildiz Y, Erturk S, Soylemez MS. A biomechanical comparison of proximal femoral nails and locking proximal anatomic femoral plates in femoral fracture fixation A study on synthetic bones. *Indian J Orthop* 2015;49:347-51.

Source of Support: TST SAN had provided the sawbones and implants, **Conflict of Interest:** None.