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Does the type and length of nail affect the stability of fixation of subtrochanteric fractures under low displacement forces?

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The treatment of subtrochanteric fractures is a highly contentious area, given the complex biomechanical properties and displacing muscle forces involved. Indeed, the debates cover almost all aspects of the treatment. Objective. To evaluate the biomechanical properties of three distinct intramedullary nails in order to identify the most reliable fixation method for subtrochanteric reverse oblique femur fractures. Methods. An osteotomy was performed in accordance with the 31A3 (intertrochanteric reverse oblique) fracture model on 24 synthetic femur bone models. Following the achievement of anatomical reduction, each group was fixed with a distinct implant system: An A-PFN (220 mm in length), an A-PFN (280 mm in length), and a cephalomedullary nail (360 mm in length). The evaluation of all models was conducted under both single and cyclic loading conditions, and an assessment of the fracture lines and total femur displacements was performed. Results. No significant correlation was observed between the groups with regard to fracture line displacement ($p > 0.05$). However, a notable distinction was evident in total femur displacement between the groups under both single and cyclic loading conditions ($p < 0.001$ and $p = 0.004$, respectively). Post-hoc analyses demonstrated that the discrepancies between the group comparisons were between the A-PFN (220 mm in length) and the other two fixation methods. Conclusions. Both short and long nails provide adequate and similar stability in an anatomically reduced reverse-oblique subtrochanteric fracture model. This suggests that anatomical reduction is more crucial than implant selection in subtrochanteric single-line fractures. While longer implants do not affect the displacement of the fracture line, they do affect the total displacement of the femur, creating a more rigid femur.

Під час лікування субтрохантерних переломів, через складні біомеханічні властивості та зміщувальні м'язові сили, суперечки виникають майже під час всіх різновидів лікування. Мета. Вивчити біомеханічні властивості трьох різних інтрамедулярних цвяхів, щоб визначити найнадійніший метод фіксації за субмеханічних зворотних косих переломів стегнової кістки. Методи. Остеотомію виконували відповідно до моделі перелому сегмента 31А3 (міжвертлюговий зворотний косий) на 24 синтетичних моделях стегнової кістки. Після анатомічної редукції кожну групу фіксували окремою системою імплантатів: A-PFN (довжиною 220 мм), A-PFN (довжиною 280 мм) та цефаломедулярним цвяхом (довжиною 360 мм). Аналіз усіх моделей проводили в умовах як одноразового, так і циклічного навантаження, а також вивчали лінії переломів і загальне зміщення стегнової кістки. Результати. Не виявлено достовірної різниці між групами щодо зміщення лінії перелому ($p > 0,05$), але була достовірна різниця в загальному зміщенні стегнової кістки між групами як за одноразового, так і циклічного навантаження ($p < 0,001$ і $p = 0,004$, відповідно). Постфактум аналіз показав, що розбіжності між порівнюваними групами були між A-PFN (довжиною 220 мм) та двома іншими методами фіксації. Висновки. Адекватну і подібну стабільність можна отримати як з короткими, так і довгими цвяхами в анатомічно зменшеній моделі зворотного косого субтрохантерного перелому, що свідчить про те, що анатомічна редукція є більш важливою, ніж вибір імплантата за субтрохантерних однолінійних переломів. Хоча довший імплантат не впливає на зміщення лінії перелому, він відбивається на загальному зміщенні стегнової кістки і створює більш жорстку стегнову фіксацію. Ключові слова. Субтрохантерні переломи, проксимальний стегновий цвях, цефаломедулярний цвях, довжина цвяха, зміщення лінії перелому, стабільність.

Keywords. Subtrochanteric fractures, proximal femoral nail, cephalomedullary nail, nail length, fracture line displacement, stability

Introduction

The subtrochanteric region, defined as the region between the trochanter minor and 5 cm distal to the trochanter, presents a significant challenge for orthopaedic surgeons, with no consensus on the optimal treatment approach. The debates encompass a multitude of aspects pertaining to the treatment of this region, largely due to the intricate biomechanical characteristics and the dynamic forces exerted by the surrounding musculature. Although there is no consensus on the specific treatment plan, there is general agreement that an intramedullary nail is the preferred implant for fractures in this region. This is due to the biological and biomechanical superiority of intramedullary fixation over plate fixation, as evidenced by several studies [1–3]. Moreover, in comparison to plate fixation, intramedullary fixation offers a number of advantages, including shorter skin incisions, reduced blood loss, decreased surgical exposure, a lower infection rate, minimal tissue damage, a shorter operative time, and the ability to begin weight bearing sooner [4–7]. Conversely, the relative merits of different intramedullary nails remain undetermined, with ongoing debate.

The prevailing opinion in the literature and clinical practice is that standard proximal femoral nails (PFNs) are the preferred option for the fixation of intertrochanteric fractures, whereas longer nails are the preferred choice in cases with subtrochanteric extension. Despite the plethora of nail lengths currently available on the market, there is a paucity of clear, well-founded literature information on the optimal length for nail use [8–10]. Conversely, a recent finite element analysis revealed that an increase in nail thickness, rather than length, resulted in enhanced stability in femoral diaphyseal fractures [11].

Objective: the objective of this study was to evaluate the biomechanical properties of three distinct intramedullary nails in order to identify the most reliable fixation method for subtrochanteric reverse oblique femur fractures under low displacement forces. Our hypothesis was that an increase in nail length would enhance stability in subtrochanteric fractures, whereas the shape of the nail would not affect stability.

Material and methods

A total of 24 synthetic femur bone models (Selbones) were utilized throughout the course of the experiment. As this study is a biomechanical evaluation of prepared bone models, approval from the ethics committee was not sought. The bones were divided into three groups, each comprising eight subjects. According to the AO / OTA classification, an osteotomy was performed in accordance with the segment 31A3 (intertrochanteric reverse oblique fracture), and an oblique fracture model was created with a cutting motor in the subtrochanteric area, just inferior level of the trochanter minor [12, 13]. Following anatomical reduction, each group was fixed with a distinct implant system (Fig. 1). In order to ensure the formation of homogeneous groups, all groups were fixed with intramedullary systems of an identical width, and all subjects were fixed with trochanter-entry systems:

– Group A was fixed with a proximal femoral nail (A-PFN, Antirotator Proximal Femur Nail, TST Orthopedics®, TST Medical Tools®), measuring 10 mm in width and 220 mm in length. A 90 mm lag screw and a 90 mm blade was used for proximal fixation and a 36 mm distal locking screw was used for distal fixation of the nail (Fig. 2).

– Group B was fixed with a longer proximal femoral nail (A-PFN, Antirotator Proximal Femur Nail, TST Orthopedics®, TST Medical Tools®), measuring 10 mm in width and 280 mm in length. Similar to the Group A, a 90 mm lag screw and a 90 mm blade was used for proximal fixation and a 36 mm distal locking screw was used for distal fixation of the nail.

Fig. 1. Distinct implant systems used in the study are shown: FIN 3-Femur Intramedullary Nail, and A-PFN, Antirotator Proximal Femur Nail

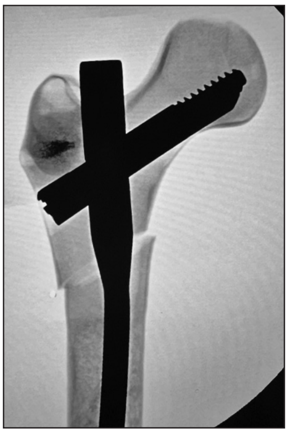

Fig. 2. The radiological image demonstrates the fixation of an A-PFN following the anatomical reduction of a reverse oblique subtrochanteric fracture model

– Group C was fixed with a cephalomedullary nail (FIN 3-Femur Intramedullary Nail, TST Orthopedics®, TST Medical Tools®), measuring 10 mm in width and 360 mm in length. A 90 mm static neck screw with a 120° angle and 70 mm dynamic neck screw with a 100° angle were used for proximal fixation and a 40 mm distal locking screw was used for distal fixation of the nail (Fig. 3).

All surgical procedures were conducted by two highly experienced trauma surgeons. Once the fixation process was complete, the synthetic bones were subjected to testing at the Dokuz Eylül University Biomechanics Laboratory. Each participant was subjected to ten cycles of cyclic compression force at 30 mm/min with a maximum force of 350 Newtons, following a single compression event. In order to ascertain the maximum force, the load borne by the femur in a bipedal walking model of an adult weighing 70 kilograms was taken into consideration. Video extensometer markers were positioned five millimeters proximal and distal to the fracture line in order to assess regional displacement (Fig. 4). Furthermore, total femur displacement was also quantified in all subjects during both single and cyclic loading. The gadget software captured the displacements and applied weight in real time. All testing was conducted using an electromechanical actuator under axial load. The eighth subject of each experimental group (the last bone model that had not undergone single or cyclic loading) was subjected to an increasing compressive force until fracture was observed (load-to-failure), and the maximum force at the point of fracture was recorded.

The statistical analyses were conducted using the International Business Machines (IBM®) Statistical Package for the Social Sciences (SPSS®) version 26.0.0.0 64-bit edition. The compliance of variables to normal distribution was examined through both visual (histogram and probability graphs) and analytical (Kolmogorov-Smirnov test) methods. The fracture line and total femur displacement parameters in the single loading group exhibited a normal distribution, whereas the fracture line and total displacement parameters in the cyclic loading group demonstrated a skewed distribution. In the descriptive statistics, mean, standard deviation and minimum-maximum range values were employed for the single loading group, whereas median, interquartile range, and minimum-maximum range values were utilized for the cyclic loading group. In the single loading group, where the variables exhibited normal distribution, the one-way ANOVA test was used for group comparisons and Tukey's LSD (Least Significant Difference) Test was preferred for post-hoc analyses. In contrast, in the cyclic loading group, where the variables displayed skewed distribution, the Kruskal-Wallis test was used for group comparisons and Mann-Whitney U-test was utilized for post-hoc analyses. The level of statistical significance was set at $p < 0.05$.

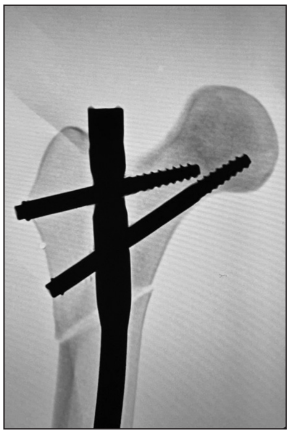

Fig. 3. The radiological image demonstrates the fixation of a FIN-3 following the anatomical reduction of a reverse oblique subtrochanteric fracture model

Results

The subjects were tested on the system in the same sequence as previously described, and the results are presented in Table 1. There was a significant difference in total femur displacement between the groups in both single and cyclic loading ($p < 0.001$ and $p = 0.004$, respectively) (Table 2). Post-hoc analyses revealed that the discrepancies between the group comparisons were between Group A (220 mm A-PFN) and the other two fixation methods. Furthermore, there was no statistically significant difference in terms of fracture line and total femur displacement between Groups B (280 mm Long A-PFN) and Group C (360 mm IMN) fixation methods (Table 3).

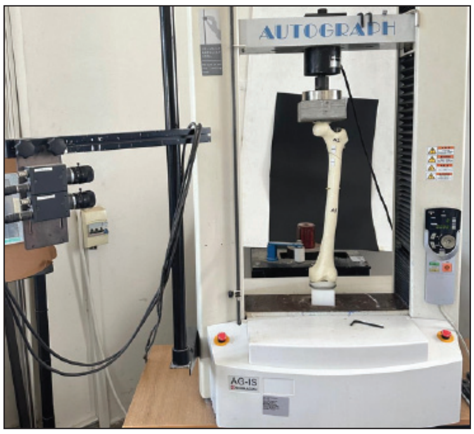

Fig. 4. The fracture models were subjected to single and cyclic loading in the biomechanics laboratory, with the fracture line and total femur displacement being measured by video extensometer

Table 1

Results of biomechanical examination of subjects

		Single Loading		Cyclic Loading	
		fracture line displacement (mm)	total femur displacement (mm)	fracture line displacement (mm)	total femur displacement (mm)
Group A: fixated with the A-PFN (220 mm)	A1	0.289	6.580	0.355	6.89
	A2	0.790	7.370	0.423	6.75
	A3	0.487	6.470	1.630	9.32
	A4	0.538	5.830	0.526	7.25
	A5	0.220	5.500	0.247	4.68
	A6	0.268	8.130	1.540	7.42
	A7	0.360	5.420	0.300	4.66
Group B: fixated with the long A-PFN (280 mm)	B1	0.342	4.920	0.059	4.33
	B2	0.880	5.560	0.944	5.88
	B3	0.229	4.510	0.183	4.18
	B4	0.978	3.840	1.002	3.86
	B5	0.120	4.670	0.271	4.75
	B6	0.710	4.679	0.524	4.26
	B7	0.475	4.870	0.410	5.09
Group C: fixated with the IMN (360 mm)	C1	0.714	3.740	0.733	4.05
	C2	0.210	3.530	0.396	3.05
	C3	0.514	3.760	0.454	3.83
	C4	0.433	3.570	0.381	3.68
	C5	0.729	4.290	0.840	4.45
	C6	0.948	3.950	0.968	3.98
	C7	0.526	4.770	0.531	5.41

Table 2

Comparative analysis of fracture lines and total displacement following single and cyclic fractures between groups

		220 mm A-PFN Fixation	280 mm Long A-PFN Fixation	360 mm IMN Fixation	P
Single Loading*	Fracture Line Displacement	0.42 ± 0.19965 (0.22–0.79)	0.53 ± 0.32980 (0.12–0.98)	0.58 ± 0.23851 (0.21–0.95)	0.514
	Total Femur Displacement	6.47 ± 1.00255 (5.42–8.13)	4.72 ± 51.491 (3.84–5.56)	3.94 ± 0.44512 (3.53–4.77)	*< 0.001*
Cyclic Loading**	Fracture Line Displacement	0.42 (1.24) (0.25–1.63)	0.41 (0.76) (0.06–1)	0.53 (0.44) (0.38–0.97)	0.558
	Total Femur Displacement	6.89 (2.74) (4.66–9.32)	4.33 (0.91) (3.86–5.88)	3.98 (0.77) (3.05–5.41)	*0.004*

Notes: statistical significance value. As the single loading group exhibited a normal distribution, mean±standard deviation (minimum-maximum range) values were employed as descriptive statistics, and the one-way ANOVA test was used for group comparisons. Conversely, as the cyclic loading group demonstrated a skewed distribution, median (interquartile range) (minimum-maximum range) values were utilized as descriptive statistics, the Kruskal-Wallis test was used for group comparisons.

We evaluated one subject from each group who had not previously been subjected to single or cyclic loading as load-to-failure. The load-to-failure forces were calculated as 882 Newton in Group A (220 mm A-PFN), 1042 Newton in Group B (280 mm Long A-PFN) and 1316 Newton in Group C (360 mm IMN), respectively. In all load-to-failure models, fractures occurred at the distal level of the nail (distal to the implant).

Discussion

The subtrochanteric region presents a significant challenge in reduction and fixation procedures due to the complex distribution of loads, which must be

Table 3

Post hoc analysis of the parameters that were found to be different in triple comparisons

	Total Femur Displacement in Single Loading (p < 0.001)			Total Femur Displacement in Cyclic Loading (p=0.004)		
	220 mm A-PFN	280 mm Long A-PFN	360 mm IMN	220 mm A-PFN	280 mm Long A-PFN	360 mm IMN
220 mm A-PFN	—	*< 0.001*	*< 0.001*	—	*0.018*	*0.004*
280 mm Long A-PFN	*< 0.001*	—	0.052	*0.018*	—	0.110
360 mm IMN	*< 0.001*	0.052	—	*0.004*	0.110	—

Notes: statistical significance value. As the single loading group exhibited a normal distribution, post-hoc analyses were performed using Tukey's LSD (Least Significant Difference) Test. Conversely, as the cyclic loading group demonstrated a skewed distribution, post-hoc analyses were performed using Mann-Whitney U Test.

taken into account in order to ensure optimal outcomes. The objective of this study was to demonstrate the biomechanical advantages of various intramedullary fixation techniques. The findings of this study will be of benefit to orthopaedic surgeons in the selection of an appropriate implant, in terms of nail type and length, for the treatment of subtrochanteric fractures. The most notable outcome of our investigation is that, despite a considerable discrepancy between the groups in total femur displacement, no statistically significant difference was observed between the internal fixation techniques in terms of fracture line displacement. Conversely, as anticipated, the total femur displacement force and load-to-failure force were found to be higher in the fixation techniques that were longer and occupied more space in the bone.

In the existing literature, two main alternatives for cephalomedullary entry nails are identified: trochanteric entry and piriformis entry. The advantages of trochanteric entry include a reduced risk of iatrogenic femoral head vascularization and femoral neck fracture in comparison to piriform fossae-entry. However, the disadvantages include abductor arm damage and a potential risk of varus malreduction [14–16]. In this experimental study, as the PFN systems used in Groups A and B were trochanteric-entry nails, we preferred to use trochanteric-entry cephalomedullary nails to ensure homogeneity between the groups.

Currently, long intramedullary nails are the recommended treatment for subtrochanteric fractures. The rationale for this approach is based on several biomechanical advantages, including enhanced stability due to a longer lever arm, and prevention of peri-implant fractures by preserving the diaphyseal area below the fracture site [9]. A recent comprehensive database study conducted in Norway recommended the inclusion of long nails in the national guideline for subtrochanteric fractures [17]. It is also common practice among authors to suggest the use of long cephalomedullary nails for the fixation of subtrochanteric fractures. However, the employment of this particular type of nail is often accompanied by an increased operative time, augmented radiation exposure, augmented bleeding, and an elevated risk of supracondylar fracture, particularly in instances of excessive femoral bowing or associated knee replacement [8, 18, 19]. The results of this experimental study, particularly those pertaining to total femur displacement, are in accordance with the findings of previous research in this field. The total femur displacement was found to be higher in the experimental group utilizing short nails (Group A) in comparison to the other experimental groups, which employed long nails (Group B and C). The latter exhibited significantly lower total femur displacement. In addition to the support and stability provided to the fracture site, the preference for long implants is an advantageous choice in preventing peri-implant fractures because it supports the diaphyseal area distal to the fracture site. Another important point to be emphasized is the femoral bowing. Interpersonal and inter-communal femoral bowing differences may be a significant disadvantage for long implant preferences. Therefore, preoperative evaluation of the patient in terms of bowing and appropriate implant preferences is of importance [20]. Unfortunately, it was not possible to evaluate femoral bowing in the context of this study. Furthermore, the present experimental study revealed no significant difference between the use of long PFNs and cephalomedullary nails with regard to both fracture line displacement and total femur displacement. This finding indicates that cephalomedullary fixation does not offer any advantage over long PFNs. However, the increased application time and technical difficulties associated with the use of cephalomedullary nails, in comparison to PFNs, represent important drawbacks [16].

Short intramedullary nails offer technical advantages, such as reduced operation and fluoroscopy time, lower blood loss, and lower cost [8, 10, 18, 20].

These advantages are undoubtedly significant, as subtrochanteric fractures are commonly observed in elderly patients due to bone fragility, advanced age, and the presence of comorbidities, or in younger individuals following high-energy traumas. In both instances, it is crucial to minimize surgical time and blood loss. Furthermore, as mentioned before, a recent finite element analysis revealed that an increase in only nail thickness, not length, results in enhanced stability in femoral diaphyseal fractures [11]. The present experimental study revealed no significant difference between the groups with regard to fracture line displacement. In light of the findings of this experimental study, short PFNs represent a valuable treatment option for anatomically reduced subtrochanteric reverse-oblique fractures. They offer a quick and simple application, minimal surgical stress for the patient and adequate stability of the fracture line.

This study has several limitations. It should first be noted that this study is based on a bone model. Given the nature of biomechanical studies, it was not possible to evaluate the effects of displacing muscle forces. However, the region under investigation is subject to significant displacing muscle forces. Consequently, further clinical studies are required to gain a full understanding of the subject. Another important limitation of our study is that, as measurements were made only under compression under single and cyclic loading, it would not be accurate to state that all three implants are equal in terms of stability required for bone union in daily practice.

Conclusions

It was demonstrated that both short and long PFNs and IMNs can provide adequate and similar stability in an anatomically reduced reverse-oblique subtrochanteric fracture model. The comparable outcomes with three distinct implants in our investigation can be attributed to the straightforward characteristics of the fracture line, anatomical reduction, and optimal implant placement (lag screw position height, etc.). This suggests that, in subtrochanteric single-line fractures, anatomical reduction is more crucial than implant selection. Although longer implants do not affect the displacement of the fracture line, they affect the total displacement of the femur and create a more rigid femur.

Conflict of interest. The authors declare no conflict of interest.

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DOES THE TYPE AND LENGTH OF NAIL AFFECT THE STABILITY OF FIXATION OF SUBTROCHANTERIC FRACTURES UNDER LOW DISPLACEMENT FORCES?

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