Original Article

The best location for proximal locking screw for femur interlocking nailing: A biomechanical study

Ahmet A Karaarslan, Ahmet Karakaşli[1], Hakan Aycan, Berivan Çeçen[2], Didem Venüs Yildiz[2], Erhan Sesli

Abstract

Background: Proximal locking screw deformation and screw fracture is a frequently seen problem for femur interlocking nailing that affects fracture healing. We realized that there is lack of literature for the right level for the proximal locking screw. We investigated the difference of locking screw bending resistance between the application of screws on different proximal femoral levels.

Materials and Methods: We used a total of 80 proximal locking screws for eight groups, 10 screws for each group. Three-point bending tests were performed on four types of screws in two different trochanteric levels (the lesser trochanter and 20 mm proximal). We determined the yield points at three-point bending tests that a permanent deformation started in the locking screws using an axial compression testing machine.

Results: The mean yield point value of 5 mm threaded locking screws applied 20 mm proximal of lesser trochanter was 1022 ± 49 (range 986–1057) (mean ± standard deviation, 95% confidence interval). On the other hand, the mean yield point value of the same type of locking screws applied on the lesser trochanteric level was 2089 ± 249 (range 1911–2268). Which means 103% increase of screw resistance between two levels ($P = 0.000$). In all screw groups, on the lesser trochanter line we determined 98–174% higher than the yield point values of the same type of locking screws in comparison with 20 mm proximal to the lesser trochanter ($P = 0.000$).

Conclusion: According to our findings, there is twice as much difference in locking screw bending resistance between these two application levels. To avoid proximal locking screw deformation, locking screws should be placed in the level of the lesser trochanter in nailing of 1/3 middle and distal femur fractures.

Key words: Femur nail, femur shaft fractures, locking screw, three-point bending test

MeSH terms: Femoral, fracture, fixation, nailing, intramedullary

Introduction

Intramedullary nailing is one of the generally accepted treatments of femoral shaft fractures.[1,2] It is often threatened by failure of locking screws, particularly on comminuted fractures. The locking nails are load-bearing devices on comminuted fractures. Hence, they have to resist full weight bearing. In load-bearing cases, the load transfer between fractured fragments is made through mainly locking screws. Early failure of locking screws with comminuted fractures may cause nonunion, malunion, delayed union, shortening, and nail migration.[3,4] Fatigue fractures of locking screws are reported with a high frequency of up to 50%.[5] The high rate of malunion in unreamed nails was correlated to frequent screw failure (52%) and nail failure (4%).[6] The application level of transverse proximal locking screw varies between the lesser trochanter and 20 mm proximal to it according to postoperative radiographs of patients from clinical application.

In material science, the yield point of the material is described as the force at which a material starts to deform plastically. The material will deform elastically and will return to its original form when the applied force is eliminated, prior to the yield point. Once the yield point is exceeded, some part of the deformation will be permanent and nonreversible. Hence, the orthopedic implants must not be exposed to forces higher than their yield points. It was reported that fatigue life was correlated to the yield point of the screws in the three-point bending tests.[7,8] Furthermore, it was reported that while walking there is

Department of Orthopedics and Traumatology, Faculty of Medicine, Şifa University, [1]Department of Orthopedics and Traumatology, Faculty of Medicine, Dokuz Eylül University, [2]Department of Biomechanics, Institute of Health Sciences, Dokuz Eylül University, İzmir, Turkey

Address for correspondence: Dr. Ahmet A Karaarslan, Department of Orthopedics and Traumatology, Faculty of Medicine, Şifa University Bornova Health Application and Research Center, Kazım Dirik Mah., Sanayi Cad., No: 7, Küçükpark-Bornova, 35040, Bornova İzmir, Turkey. E-mail: aakaraarslan@yahoo.com

Access this article online

Quick Response Code:

Website: www.ijoonline.com

DOI: 10.4103/0019-5413.173508

a 2060 N (2.8 body weight [BW]) peak axial loading on the femur shaft for a 75 kg person and a 2280 N (3.1 BW) peak axial loading, while going down the stairs.[9,10] For early level walking in comminuted femur fractures treated with locked nailing, for the proximal locking screws not to deform plastically the yield points of the screws must be higher than 2060 N (2.8 BW). In some studies, it is clarified that three-point bending test values decrease when the transcanalicular working length of the screw increases.[11-13] However, we couldn't find any studies that compare the true yield points of locking screws for lesser trochanter and 20 mm proximal to it. Our study is the first to seek the appropriate trochanteric level that doesn't cause locking screw deformation on level walking for comminuted and oblique femur diaphysis fractures.

The hypothesis of this study was that the proximal locking screw bending resistance was higher in the lesser trochanter level where the canal is narrower than 20 mm proximal of it. The trochanteric level is more suitable for locking screw insertion. Furthermore, the locking screws applied to lesser trochanter level can resist to 2.8 BW (2060 N) of load while the locking screws applied 20 mm proximal of the lesser trochanter aren't able to. Is there significant difference of locking screw bending resistance between the application of screws on the lesser trochanteric level or 20 mm proximal of it? Which type of proximal locking screws can resist to 2.8 BW (2060 N) of load in load bearing conditions?

Materials and Methods

We performed three-point bending tests on four types of screws with two different dimensions (5 mm and 5.5 mm) and with two different thread length (full and 17 mm tip thread) in two different trochanteric levels (the lesser trochanter line and two cm above the lesser trochanter).

We used 80 medical stainless steel (316 L) (manufactured by Hipokrat Medical Devices, Izmir, Turkey) proximal locking screws for eight groups, ten screws for each group [Table 1]. Smooth screws were only 17 mm tip threaded. All fully threaded screws had a low profile high pitch thread. We used two metal cylinders, one of them representing trochanteric level and the other representing 20 mm proximal of it. The inner and outer femoral cortex diameters were 30–45 mm on the level of lesser trochanter and 45–55 mm 20 mm proximal of lesser trochanter according to previous studies.[14-17] We designed the inner and outer diameters of these two metal cylinders according to femur measurements on previous studies. In groups 1, 3, 5, and 7 a metallic stainless steel cylinder (inner diameter of 45 mm, outer diameter 55 mm and length 440 mm) that mimicked the level of the femur, 2 cm above the lesser trochanter was used. In the second, fourth, sixth and eighth groups, a second metallic cylinder (inner diameter 30 mm, outer diameter 45 mm and length 440 mm) that mimicked the level of the femur on the lesser trochanter was used. 2 cm below their tip were two opposite holes with a diameter of 6.5 mm. A locked nail (Tıpsan Medical Devices Company, Izmir, Turkey) that was 380 mm in length, the proximal part of which was 13 mm in diameter with a 12 mm body diameter, was used for the three-point bending test. There is an oblong proximal locking screw hole which is 12 mm long and 6 mm wide 60 mm distal from the locked nail proximal edge. The nail was supported by two rings proximally and distally in case the locking nail should not move to the sides in the metal cylinder [Figure 1]. The rings, of which the outer diameter was 2 mm smaller

Table 1: Screw groups (geometry, deformation on the yield point and stiffness) tested in 3-point bending test at the lesser trochanter level (30 mm span) and 20 mm proximal of it (45 mm span)

Screw groups (n=10)	Core diameter (mm)	Total length (mm)	Mean±SD	
			Deformation on yield point (mm)	Stiffness N/mm
Group: 5 mm threaded screw in 45 mm span	4,5	70	1.34±0.017	839±127
Group: 5 mm threaded screw in 30 mm span	4,5	55	1.04±0.1	2423±247
Group: 5 mm smooth screw in 45 mm span	-	70	0.93±0.25	1174±215
Group: 5 mm smooth screw in 30 mm span	-	55	1.01±0.12	3689±165
Group: 5,5 mm threaded screw in 45 mm span	5	70	0.90±0.08	1328±55
Group: 5,5 mm threaded screw in 30 mm span	5	55	1.1±0.19	2727±449
Group: 5,5 mm smooth screw in 45 mm span	-	70	0.87±0.06	2003±104
Group: 5,5 mm smooth screw in 30 mm span	-	55	0.84±0.09	4511±300

N=Newton, SD=Standart deviation

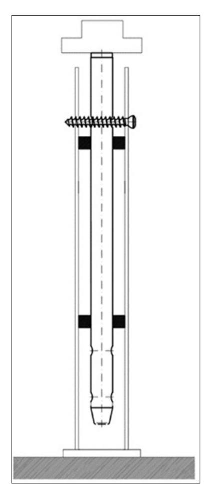

Figure 1: Proximal locking screw three-point bending test

than the inner diameter of the cylinder, had 15 mm inner diameter, with a height of 10 mm. After two rings had been put on the nail by three screws, their free movement distally and proximally in the cylinder was checked. The screws to be tested were passed through metal cylinder holes which had a 6.5 mm diameter and a proximal locking screw hole of the nail [Figures 1 and 2]. The whole load is transferred from the proximal to distal in this experiment assembly through the proximal locking screw. There is no load sharing situation, instead a load bearing condition that imitate comminuted femur fractures.

The study was conducted in the Biomechanics Laboratory of our institute. The biomechanical tests were performed using the axial compression testing machine (AG-I 10 kN, Shimadzu, Japan). In this study, the loading rate was 1 mm/min in displacement control mode.[7,8] The loading was made on the head of the nail [Figures 1 and 2]. In the current study, we studied the yield point of the stainless steel screw in this experimental design. The machine output force-displacement graphs on the computer monitor. During the biomechanical test period, bending in the elastic-plastic deformation border was determined in the force-strain graph. By visualizing the graphs, we detected the yield point after the straight line became curve. Then, we stopped the test. After every experiment, we checked all screws and nails macroscopically. All of the screws were bent in the middle of the screw on the compression site and did not have any fracture.

The data of the yield point values at the three-point bending test were evaluated using the Mann–Whitney U-test using SPSS software (version 15.0 for Windows, IBM Corp., NY, USA). The level of significant difference was defined as $P < 0.05$.

Figure 2: Application of the test on the axial compression testing machine

Results

We found the yield point values occurring in the line of the lesser trochanter to be 2 times more (on average, 98–174%) than the yield point 20 mm proximal to the lesser trochanter ($P = 0.000$) [Table 2]. We found the lowest yield point as 1022 ± 49 (range 986–1057) N in 5 mm diameter fully threaded screws in 20 mm proximal to the lesser trochanter [Table 2]. We found the highest yield point as 3532 ± 255 (range 3349–3714) N in smooth 5.5 mm diameter smooth screws in the line of the lesser trochanter [Table 2].

20 mm proximal to the lesser trochanter we determined the yield points at three-point bending test of all locking screw groups below 2060 N [Table 2]. In the lesser trochanter line, we determined the yield points of 3 locking screw groups (5.5 mm diameter fully threaded screws, 5.5 mm diameter smooth screws and 5 mm diameter smooth screws) above 2060 N [Table 2]. We determined that the yield points of 5 mm diameter fully threaded screws was critical as 2089 ± 249 (range 1911–2268) N in terms of 2060 N axial loading to femur.

Discussion

There is twice as much difference in locking screw bending resistance between lesser trochanter level and 20 mm proximal of it. To allow early weight bearing in femur fractures, proximal locking screws must be placed at the level of the lesser trochanter. Placing the locking screw 20 mm proximal to the lesser trochanter must not be used.

According to our findings, the greatest factor which determines the proximal locking screw three point bending strength was the femur canal diameter (i.e., transcanalicular working length of the locking screw). While the diameter of the channel increased, the yield point value decreased fast.

Table 2: The comparison of values of the yield points (mean±SD; 95% CI) at 3-point bending test between 20 mm proximal to the lesser trochanter in 40 screws and lesser trochanter line in 40 screws

Screws	(*n*=40) *N*, Mean±SD (95%CI)		*P* (based on Mann-Whitney U test)
	20 mm proximal to the l.t. (45 mm span)	Lesser trochanter level (30 mm span)	
5 mm threaded	1022±49 (986-1057)	2089±249 (1911-2268)	*P*=0,000 Increase: 103%
5 mm smooth	1164±337 (922-1406)	3190±246 (3013-3366)	*P*=0.000 Increase: 174%
5.5 mm threaded	1186±139 (1086-1286)	2760±387 (2484-3037)	*P*=0,000 Increase; 132%
5.5 mm smooth	1775±122 (1688-1862)	3532±255 (3349-3714)	*P*=0,000 Increase: 98%

N=Newton, SD=Standart deviation, CI=Confident interval, l.t=Lesser trochanter

Our findings showed that in the line of the lesser trochanter, the yield point of the locking screws was at least two times higher than in 20 mm proximal to the lesser trochanter in all groups. It's reported that when transcananicular working length of the locking screw decreases, the yield point strength at 1 mm three-point bending deformation increases.[11-13] Chao *et al*.,[7] Hou *et al*.[8] and Lin and Hou[18] measured single loading yielding strength value with 1 mm deformation and also cyclic loading fatigue life of screws in the three point bending test using a polyethylene cylinder which had a 30 mm inner diameter. Aper *et al*. applied a three point bending test in aluminum tubes of 19 mm and 31.8 mm inner diameter with cortical screws that were 2.7 mm in diameter.[12] When the tube's inner diameter increased, less frequent cyclic loading was required for screw failure. At the level of the femur's lesser trochanter, thin but short and transverse locking screws showed higher bending strength than thick inclined screws.[11]

As in the test with the polyethylene cylinder, the pull out and holding power of the locking screw came into play, making yield point determination impossible. Instead of yield point determination, the locking screw three point fatigue life tests were mostly performed.[19,20] In their cylinders, the holes were not bigger than the screw diameter. Therefore, the pull-out and holding power of the locking screws could not be eliminated. They measured the force around the point of 1 mm deformation, which was defined as the "yielding strength" instead of the "true yield point."[7,8,18] We also determined that the holes in the metal cylinder started to apply a holding power effect on the thread of locking screws when the screw bended. We concluded that the diameter of the smallest metal cylinder screw hole must be 6.5 mm in order to state the yield point clearly.

Locking nails work as full load bearing implants on comminuted, oblique femur fractures and high energy fractures that bone resorption on the fracture site is frequently seen. In these fractures, for early weight bearing proximal locking screws must resist BW loading. Taylor *et al*. reported that there was peak axial load of 2280 N (3.1 BW) on the femur while going down the stairs and that there was peak axial load of 2060 N (2.8 BW) on the femur during level walking for a 75 kg person.[9,10] For comminuted femur fractures in level walking; for the proximal locking screws not to deform plastically, the yield points of these locking screws must be higher than 2060 N. By the result of our study we determined that the yield points of all locking screws groups (5 mm, 5.5 mm threaded, unthreaded) were below 2060 N, on the level of 20 mm proximal to the lesser trochanter. We determined that the 5 mm or 5.5 mm diameter smooth locking screw and the 5.5 mm diameter fully threaded locking screw, which is applied only in the line of the lesser trochanter, could resist up to 2060 N of axial loading. According to our results, there may be failure in all screws placed 20 mm proximal to the lesser trochanter in level walking for load bearing nails. Eventually, the reduction of the fractures fail. Deformity, shortness and nonunion may be the result.

In this study the loads were applied on the nail vertically, in a complicated experimental assembly imitating physiological nonvertical or angled forces, it would be impossible to determine the exact yield points of a lock screw. It is limitation of our study that we didn't use composite femur, but in a test assembly with that material, we found out that it's impossible to find out the sudden deformation that appear on the force deformation graph belongs to which locking screw deformation (one proximal and two distal locking screws). We found out that deformations appear on the fixation points of composite femur and the test machine. Also deformations appear on the holes of the screws on composite femur during the three-point bending tests. So that it was uncertain if the deformation that appears on force-deformation graph, belonged to these deformations or the screw deformation itself. We discovered that a very little deformation like 0.1 mm affects the test seriously and makes it impossible to determine the exact yield point. Materials like cadaver femur, poliethilene or aluminum cylinders could be used for this study. However, holes of polyethylene cylinder or cadaver femur can also be deformed during three-point bending tests. So that it's impossible to differ screw deformation from the cylinderic material deformation or holes of it. We searched for the perfect experiment system that would allow us to determine the exact yield points of the screws. That's why we used stainless steel cylinders, holes of which and itself cannot be deformed.

Clinically, a short distance between the screw location and the fracture site may be presumed as the cause of a larger bending stress on the screw nail interface, so in femur proximal shaft fractures inserting the proximal lock screw higher is more appropriate.

Consequently, in intramedullary nailing of femur middle 1/3 and distal fractures, a proximal locking screw should be placed in the level of the lesser trochanter. 20 mm proximal to the lesser trochanter level may be used for proximal femur shaft fractures.

References

1. Colchero F, Orst G, Reboul C, Villalobos F, Vidal J. Intramedullary locking nailing. Experimental study. Surgical technic. Results. Rev Chir Orthop Reparatrice Appar Mot 1983;69:547-55.
2. Kempf I, Grosse A, Taglang G, Favreul E. Gamma nail in the treatment of closed trochanteric fractures. Results

and indications of 121 cases. Orthop Traumatol Surg Res 2014;100:75-83.
3. Whittle AP, Wester W, Russell TA. Fatigue failure in small diameter tibial nails. Clin Orthop Relat Res 1995;315:119-28.
4. Boenisch UW, de Boer PG, Journeaux SF. Unreamed intramedullary tibial nailing – Fatigue of locking bolts. Injury 1996;27:265-70.
5. Whittle AP, Russell TA, Taylor JC, Lavelle DG. Treatment of open fractures of the tibial shaft with the use of interlocking nailing without reaming. J Bone Joint Surg Am 1992;74:1162-71.
6. Court-Brown CM, Will E, Christie J, McQueen MM. Reamed or unreamed nailing for closed tibial fractures. A prospective study in Tscherne C1 fractures. J Bone Joint Surg Br 1996;78:580-3.
7. Chao CK, Hsu CC, Wang JL, Lin J. Increasing bending strength of tibial locking screws: Mechanical tests and finite element analyses. Clin Biomech (Bristol, Avon) 2007;22:59-66.
8. Hou SM, Wang JL, Lin J. Mechanical strength, fatigue life, and failure analysis of two prototypes and five conventional tibial locking screws. J Orthop Trauma 2002;16:701-8.
9. Taylor SJ, Walker PS, Perry JS, Cannon SR, Woledge R. The forces in the distal femur and the knee during walking and other activities measured by telemetry. J Arthroplasty 1998;13:428-37.
10. Taylor SJ, Walker PS. Forces and moments telemetered from two distal femoral replacements during various activities. J Biomech 2001;34:839-48.
11. Kinast C, Frigg R, Perren SM. Biomechanics of the interlocking nail. A study of the proximal interlock. Arch Orthop Trauma Surg 1990;109:197-204.
12. Aper RL, Litsky AS, Roe SC, Johnson KA. Effect of bone diameter and eccentric loading on fatigue life of cortical screws used with interlocking nails. Am J Vet Res 2003;64:569-73.
13. Karuppiah SV, Johnstone AJ. How cross screw length influences the stiffness of intramedullary nail sistem. J Biomed Sci Eng 2010;3:35-8.
14. Umer M, Sepah YJ, Khan A, Wazir A, Ahmed M, Jawad MU. Morphology of the proximal femur in a Pakistani population. J Orthop Surg (Hong Kong) 2010;18:279-81.
15. Sen RK, Tripathy SK, Kumar R, Kumar A, Dhatt S, Dhillon MS, *et al.* Proximal femoral medullary canal diameters in Indians: Correlation between anatomic, radiographic, and computed tomographic measurements. J Orthop Surg (Hong Kong) 2010;18:189-94.
16. Rubin PJ, Leyvraz PF, Aubaniac JM, Argenson JN, Estève P, de Roguin B. The morphology of the proximal femur. A three-dimensional radiographic analysis. J Bone Joint Surg Br 1992;74:28-32.
17. Noble PC, Alexander JW, Lindahl LJ, Yew DT, Granberry WM, Tullos HS. The anatomic basis of femoral component design. Clin Orthop Relat Res 1988;235:148-65.
18. Lin J, Hou SM. Bending strength and holding power of a prototype tibial locking screw. Clin Orthop Relat Res 2002;403:232-9.
19. Gaebler C, Stanzl-Tschegg S, Heinze G, Holper B, Milne T, Berger G, *et al.* Fatigue strength of locking screws and prototypes used in small-diameter tibial nails: A biomechanical study. J Trauma 1999;47:379-84.
20. Griffin LV, Harris RM, Zubak JJ. Fatigue strength of common tibial intramedullary nail distal locking screws. J Orthop Surg Res 2009;4:11.

How to cite this article: Karaarslan AA, Karakasli A, Aycan H, Cecen B, Yildiz DV, Sesli E. The best location for proximal locking screw for femur interlocking nailing: A biomechanical study. Indian J Orthop 2016;50:94-8.

Source of Support: Nil, **Conflict of Interest:** None.