Acta Orthop. Belg., 2015, **81**, 245-250

ORIGINAL STUDY

A new compression design that increases proximal locking screw bending resistance in femur compression nails

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The aim is to present our new method of compression, a compression tube instead of conventional compression screw and to investigate the difference of proximal locking screw bending resistance between compression screw application (6 mm wide contact) and compression tube (two contact points with 13 mm gap) application. We formed six groups each consisting of 10 proximal locking screws. On metal cylinder representing lesser trochanter level, we performed 3-point bending tests with compression screw and with compression tube. We determined the yield points of the screws in 3-point bending tests using an axial compression testing machine. We determined the yield point of 5 mm screws as 1963 ± 53 N (mean ± SD) with compression screw, and as 2929 ± 140 N with compression tubes. We found 51% more locking screw bending resistance with compression tube than with compression screw (p = 0,000). Therefore compression tubes instead of compression screw must be preferred at femur compression nails.

Keywords : femoral shaft fractures ; compression nail ; femur locking screws ; bending test.

INTRODUCTION

In the treatment of femur fractures, nailing with compression have been reported to have higher stability (*3,6,8,13,14,19,22*). As the compression increases in the fracture line, fracture union rate increases. The failure of the locking screw is primarily caused by a bending force at the middle part of the screw produced by loading of the nail. Load transfer between fracture fragments is mainly over locking screws. In compression nailing the weakest site of the bone-implant construct is the contact site of locking screw to nail. Proximal locking screw deformation is frequently seen (*19*). It is reported that proximal locking screw deformation can occur even in the operation room (*22*). The screw failure may be the result of a single deforming load or cyclic loading. Early failure of locking screws may cause nonunion, malunion, delayed union, shortening and nail

No benefits or funds were received in support of this study. The authors report no conflict of interests.
This study was carried out in Şifa University Bornova Health Application and Research Center – Bornova, İzmir, Turkey.

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migration (*2,21*). Fatigue fractures of locking screws are reported with high frequency up to 50% (*20*). The high rate of malunion in unreamed nails is correlated to the frequent screw failure (52%) and nail failure (4%) (*5*).

In material science, the yield point of a 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 non-reversible. 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 strength of the screws in the 3-point bending tests (*4,10*).

In femur compression nailing, compression screw is in contact with the proximal locking screw at 5-6 mm area while in standard interlocking intramedullary nailing, nail body is in contact with the proximal locking screw at two points with 13 mm gap. There are no clinical trials or 3-point bending tests that show the bending resistance difference between "two contact points with 13 mm gap" and "5-6 mm contact area". We designed this study to investigate the effect of contact area difference on locking screws. Our novel compression tube compresses on proximal locking screw from two separate points with 13 mm gap. We performed 3-point bending tests to compare the resistance on the locking screws with 6 mm contact area (nail with compression screw) and with two contact points with 13 mm gap (with compression tube).

The hypothesis of our study was that we can obtain more proximal locking screw bending resistance with the compression tube because of two separate contact points with 13 mm gap on proximal locking screw instead of 6 mm contact of compression screw. Does proximal locking screw bending resistance decrease on compression nail with compression screws comparing to conventional interlocking nails ? Does proximal locking screw bending resistance increase on nails with compression tube (two contact points with 13 mm gap) comparing to nails with compression screw (6 mm contact area) ?

MATERIALS AND METHODS

This prospective randomised comparative study has level II of evidence grade.

On the metal cylinder representing lesser trochanter level, 3-point bending tests were applied to 5 mm and 5.5 mm diameter smooth (unthreaded) proximal locking screws with standart locking nail, nail with compression screw and the nail with compression tube.

We used total sixty medical stainless steel (316 L) proximal locking screws (produced by Hipokrat medical devices company-İzmir/Turkey)) for six groups, ten screws for each group. All of the screws had no thread and their length were 70 mm. We used a metallic cylinder (inner diameter 30 mm, outer diameter 45 mm) which mimicked the level of lesser trochanter. We determined the inner diameter of the metal cylinders that represent the lesser throchanter level by literature support (*15,16,17,18*). We used the same three-point bending experimental assembly that previous researchers had used (*4,10*). There were two opposite 6.5 mm diameter holes two cm below of the top of the cylinder.

A conventional interlocking nail (Tıpsan medical devices company-İzmir/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 3-point bending tests. There was an oblong proximal locking screw hole which is 12 mm long and 6 mm wide 60 mm distal from the nails proximal edge (Fig. 1a). The locking screws were compressed with 13 mm nail body contact inside the oblong holes. We used ten 5 mm locking screws and ten 5.5 mm smooth locking screws with conventional interlocking nail (Table I).

The nail with compression screw (produced by Tıpsan medical devices company-İzmir/Turkey) had an oblong hole (6 mm. wide and 15 mm. long) in the proximal part. We positioned the compression screw in the middle of the oblong hole (Fig. 1b). We performed three-point bending tests with the compression screw on 5 mm and 5.5 mm smooth screw groups (Table I). The width of distal end of the compression screw was 6 mm (6 mm contact area). Compression screw was 48 mm in length.

The nail with compression tube (produced by Tıpsan medical devices company-İzmir/Turkey) also had an oblong hole (6 mm wide and 20 mm long) in the proximal part. Compression tube was 51 mm in length and 13 mm in width (Fig. 1c). As its central screw is rotated, the compression tube shifts distally and pushes the proximal locking screw distally inside the oblong holes of the nail. Because the distance between the proximal locking screws and the distal locking screws shortens, a compres-

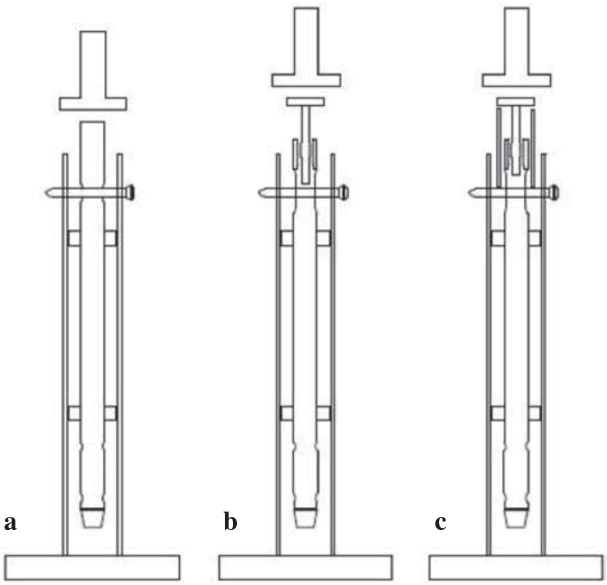

Fig. 1. — a. Interlocking nail. b. Compression nail with compression screw. c. Compression nail with compression tube at three-point bending test.

sion occurs at the fracture site (Fig. 2a,b). Screws to be tested passed through 6.5 mm diameter holes of metal cylinders and proximal oblong hole of the nail. By rotating the compression screw, the compression tube moved 10 mm distally inside the proximal oblong hole of the nail. Having placed ten 5 mm smooth locking screws and ten 5.5 mm smooth locking screws, bending test was performed (with two separate contact points with 13 mm gap) (Fig. 1c, 3).

The study was conducted in Biomechanics Laboratory, Institute of Health Sciences, University of Dokuz Eylül. The biomechanical tests were performed by using the axial compression testing machine (AG-I 10 kN, Shimadzu, Japanese). In 3 point-bending tests, loading at a speed of 1 mm/min were done *(4,10)*. In this study, loading was done from nail top (Fig. 2, 3). We determined yield points of stainless steel screws in this experimental design. The machine outputted force-displacement graphs on computer monitor and we identified the elastic-plastic deformation border in the force-strain graphs. We visualized the graphs, after straight line became curve we detected the yield points. Then we stopped the test. After every experiment we checked all screws and nail macroscopically. Screws were bent in one of the two contact sites of the compression tube and haven't had any fractures. Screws were bent in the middle with compression screw and interlocking nail body. In compression screw, the compression tube and nail, there was no deformity. Stiffness was calculated according to straight line on force-strain graphs.

The data of the yield point values at the 3-point bending tests were evaluated using the Mann-Whitney U test by SPSS software (ver.15.0 for Windows). The level of significant difference was defined as $p < 0.05$.

RESULTS

First we compared proximal locking screw bending resistance between conventional interlocking nail and compression nails with compression screws. We found that proximal locking screw resistance has decreased 62% with 5 mm locking screws and 35% with 5.5 mm locking screws by the compression screw (P = 0,000) (Table II).

Secondly we compared proximal locking screw bending resistance between the nail with compres-

Table I. — Deformation on the yielding point (mm) and stiffness (N/mm) of proximal locking screws with conventional interlocking nail body (13 mm Wide), compression screw (6 mm wide) and compression tube (13 mm wide)

Screw groups Unthreaded	Compressed with	Deformation on the yielding point (mm) Mean ± SD	Stiffness (N/mm) Mean ± SD
5 mm screws (n = 10)	nail body	1.01 ± 0.12	3689 ± 165
5 mm screws (n = 10)	screw	0.50 ± 0.01	3856 ± 85
5 mm screws (n = 10)	tube	0.62 ± 0.04	4708 ± 134
5.5 mm screws (n = 10)	nail body	0.84 ± 0.09	4511 ± 300
5.5 mm screws (n = 10)	screw	0.73 ± 0.11	3858 ± 534
5.5 mm screws (n = 10)	tube	0.68 ± 0.04	5791 ± 192

N: Newton.

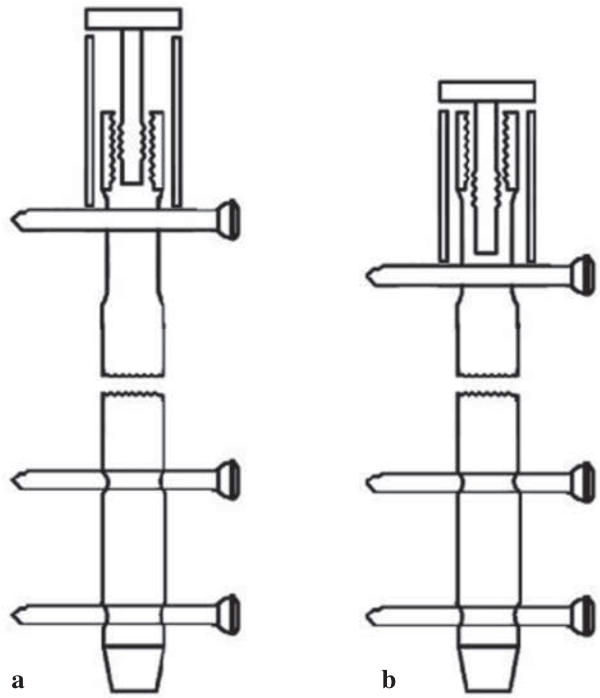

Fig. 2. — a. Before. b. After compression with compression tube.

Fig. 3. — Three-point bending test of the nail with compression tube using an axial compression testing machine.

sion screw and the nail with compression tube. We found that proximal locking screw resistance has increased 49% with 5 mm locking screws and 51% with 5.5 mm locking screws with the compression tube (P = 0.000) (Table III).

We found the lowest yield point as 1963 ± 53 (1929-1997) N, mean ± SD) at 5 mm diameter screws on the nail with compression screw (Table II). We found the highest yield point as 3943 ± 211(3809-4077)N at 5.5 mm diameter screws on the nail with compression tube (Table III).

DISCUSSION

The first aim of our study was to find out if there is locking screw bending resistance difference between conventional interlocking nail and the nail with compression screw. According to our findings proximal locking screw resistance of conventional interlocking nailing was superior to the nail with compression screw. There is 35-62% difference.

The second and more important aim of our study was to justify the fact that there is significant bending resistance difference between applying the proximal locking screw with compression screw or with our novel compression tube. According to our findings the proximal locking screws of the nail with compression tube were about 50% more resistant comparing to nail with compression screw.

With respect to the locking screw resistance at 3-point bending tests, it is important if the load is onto a narrow contact (5 or 6 mm wide) or onto two points (13 mm wide). In all groups, the screws applied with broad contact or with two point contact (13 mm wide) have showed approximately 35-62% more resistance than the screws applied with narrow contact (6 mm contact). Compression screws with 5 mm tips are generally used in most available compression nails. In our experiment the tip of the compression screw was 6 mm diameter. We assume that

Table II. — The Comparison of the Yield Points of Proximal Locking Screws Placed on the Lesser Trochanter Level on a Standard Locking Nail (13 mm wide contact) with the Locking screws on a Nail with Compression Screw (6 mm contact) at Three-Point Bending Test

Screw groups Unthreaded	The yield point with standart locking nail (n = 20) (Mean ± SD, 95%CI N)	The yield point with compression screw (n = 20) (Mean ± SD, 95%CI N)	P
5 mm screws	3190 ± 246 (3013-3366)	1963 ± 53 (1929-1997)	P = 0.000 Decrease : 62%
5.5 mm screws	3532 ± 255 (3349-3714)	2600 ± 228 (2456-2744)	P = 0.000 Decrease : 35%

N : Newton.

if we used compression screw with 5 mm diameter tip, the proximal locking screw resistance could be even lower.

We found that compression to the locking screw near the bone cortex with two different points or with broad contact had more advantage. As the distance between the sides of compression tube (or convensional nail body) and bone cortex decreases, screw bending resistance increases.

It was reported that short thin transverse screws show more bending resistance than long oblique thick screws in trochanteric area (*12*). It was reported that as the channel diameter that the screw spanned increase, screw bending resistance decrease (*1,11*). Due to the 13 mm diameter of the compression tube or conventional nail body, compression points to proximal locking screw approaches to the cortex and the lever arm is shortened.

Hou *et al* (*10*) and Chao *et al* (*4*) have reported lower values on bending tests of screws on 30 mm inner diameter polyethylene cylinder. In their test the pressure to screws was right on the center on a single point (1 mm wide). Decreased 3-point bending strength was reported on one mm deformation by them. In our experiment assembly which imitates the practical application, the pressure was from the distal tip of compression screw, 6 mm in width. The pressure was from 2 points which are very close to the bone cortex with a 13 mm distance to the locking screw by compression tube.

If the screw diameter is close to the cylinder hole diameter, the yield point determination is hard as the holding power of locking screw gets into action. For this reason locking screw three-point fatigue tests are preferred (*1,4,7,9*). We found that, in cylinders with holes with diameter not much bigger than screw diameters, with the bending deformation of screws, holes start to apply holding power effect to the locking screws. We clarified that, for a precise determination of yield point, the minimum screw hole diameter must be 6.5 mm.

It may seem as a limitation of our study that we didn't use fourth generation composite femur. In a test assembly with that material, there is also defor-

Table III. — The Comparison of the Yield Points of Proximal Locking Screws Placed on the Lesser Trochanter Level on a Nail with Compression Screw (6 mm contact) with the Locking screws on a Nail with Compression Tube (2 contact points with 13 mm gap) at Three-Point Bending Test

Screw groups Unthreaded	The yield point with compression screw (n = 20) (Mean ± SD, 95%CI N)	The yield point with compression tube (n = 20) (Mean ± SD, 95%CI N)	P
5 mm screws	1963 ± 53 (1929-1997)	2929 ± 140 (2842-3016)	P = 0.000 Increase : 49%
5.5 mm screws	2600 ± 228 (2456-2744)	3943 ± 211 (3809-4077)	P = 0.000 Increase : 51%

N : Newton.

mation on composite femur and the test assembly, it's impossible to find out the deformation that appear on the force-deformation graph belongs to screw deformation or others. In this study we could also use materials like cadaver femur, poliethilene or aluminium cylinders. Holes of polyethylene cylinder or cadaver femur deform too. We found out that a minimal deformation like 0.1 mm on the test material holes or anywhere other than screws lead to the failure of the experiment and makes it impossible to determine the exact yield point. That's why we used stainless steel cylinders, holes of which can not be deformed during the three-point bending test. We preferred unthreaded smooth locking screws because the threads of screws may have an impingement affect on the holes and we could have problems obtaining the exact yield points.

As a conclusion, for about 50% more proximal locking screw resistance, our novel nail with compression tube must be preferred instead of femoral nails with compression screw.

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