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EXPERIMENTAL DETERMINATION OF BONE CORTEX HOLDING POWER OF ORTHOPEDIC SCREW

Raul Bolliger Neto, João D. M. B. Alvarenga Rossi and Tomaz Puga Leivas

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BOLLIGER Neto, R. - Experimental determination of bone cortex holding power of orthopedic screw. **Rev. Hosp. Clín. Fac. Med. S. Paulo 54** (6): 181-186, 1999.

SUMMARY: Cylindrical specimens of bone measuring 15 mm in diameter were obtained from the lateral cortical layer of 10 pairs of femurs and tibias. A central hole 3.2 mm in diameter was drilled in each specimen. The hole was tapped, and a 4.5 mm cortical bone screw was inserted from the outer surface. The montage was submitted to push-out testing up to a complete strip of the bone threads. The cortical thickness and rupture load were measured, and the shear stress was calculated. The results were grouped according to the bone segment from which the specimen was obtained. The results showed that bone cortex screw holding power is dependent on the bone site. Additionally, the diaphyseal cortical bone tissue is both quantitatively and qualitatively more resistant to screw extraction than the metaphyseal tissue.

DESCRIPTORS: **Bone and bones. Biomechanics. Bone screw. Tension resistance.**

Several traditional methods for internal osteosynthesis use screws or plates to fix bone fragments. With the development of new surgical techniques and new implant materials, various investigations have been performed to improve different osteosynthesis methods. The effects of screw size and implant techniques of orthopedic screws in cortical bones on the shearing resistance have been investigated for this purpose.

The current literature reports that required screw extraction strength is linear to bone thickness.[3] Extraction strength is dependent on implant location site,[2] and it is remarkably dependent on the screw diameter.[6] *In vivo* studies have shown that extraction resistance increases up to 1.5 to 1.9 times at the 6th post-implant week, then it decreases to 1.2 to 1.6 times at the 12th post-implant week.[6] This reduction is thought to be caused by movement-induced bone resorption around the screw[7]. Uhthoff has shown in histology studies that the screw-to-bone surface contact is greater with self-tapping screws as opposed to non-self-tapping screws[8]. Despite this difference, the bone holding power for these different screws was not statistically significant[3,9].

Reports in the literature recommend the use of wide screws[4] with a core diameter of at least 3 mm[1].

Investigations of screw holding power should control for the following variables: the bone into which the screw is implanted, the variability of the bone tissue at the implant location, and bone mechanical properties.

The objective of this study was to analyze the variations in the mechanical resistance of the metaphyseal and diaphyseal cortical bone tissue in the femur and tibia to push-out forces on an orthopedic screw.

MATERIAL AND METHOD

Cylindrical cortical bone samples (15 mm diameter) were obtained from the lateral surface of 10 pairs of femurs and tibias. The bone samples were cut so their longitudinal axis was perpendicular to the bone surface. The bone samples were sequentially carved from the distal femur metaphysis and from the proximal tibia metaphysis towards the diaphysis of both bones. A distance of 25 mm was set between two consecutive bone samples. Tibia and femur bicondylar diameters were recorded, and the distance from the longitudinal axis to the distal femur articular surface and proximal tibia articular surface were also recorded (Fig. 1).

From the Institutes of Orthopedics and Traumatology, University of São Paulo School of Medicine, São Paulo – Brazil.

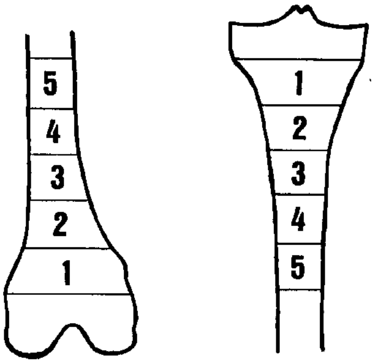

Figure 1 - Bone segmentation in femur and tibia.

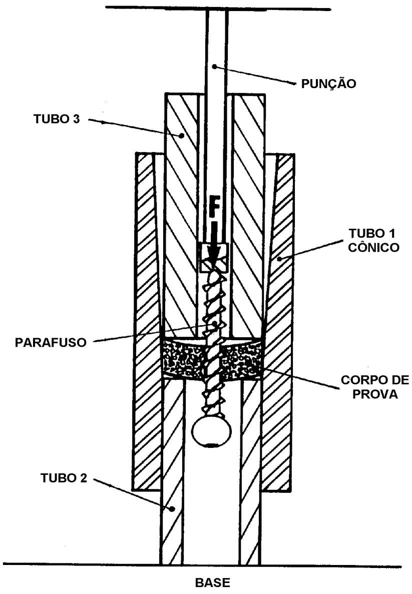

Figure 2 - Mechanical assay scheme.

A bench drilling machine was used to drill a longitudinally-centered 3.2 mm diameter hole in each bone sample. The cortical bone thickness at the level of the hole was measured with a micrometer. The internal surface of the hole was fitted with a 4.5 mm diameter tap. A cortical spherical-head AO kind screw (Arbeitsgemeinschaft für den Ostheosynthesenfragen) with an internal six-faced slot, with external and core diameter of 4.5 mm and 3.0 mm, respectively, and having a 1.75 mm long thread and screw length of 35 mm was employed. The screw head was on the external cortical surface.

This testing unit was inserted into a metallic tube with a slightly conical internal surface (tube one) with the screw head facing down. Testing unit placement inside tube one served to prevent cortical layer rupture during push-out testing. A second tube (tube two) was placed upwards inside tube one to support the testing unit from the external surface, leaving a free passage for the screw. A third tube (tube three) was placed from the top, surrounding the screw end. This entire montage was centered under the loading anvil of a Kratos 5002 model machine with a load CCT of 10 TF (Fig. 2). A push-out load at 20 mm/minute was applied on the screw end. A 790 BBC Goerz Metrawatt Servogor graphic recorder plotted the maximal shearing resistance or maximal cortical layer stripping force.

Shearing tension was calculated for each testing unit using the following formula:

Shearing tension = rupture load/[(thickness) x (screw external diameter) x π].

The testing units were positioned taking into account the distances from the articular surface to their centres. In order to overcome size differences among the bones, relative distances, calculated using the expression below, were used.

Relative distance = [(real distance) x (average bicondylar diameter)]/(bone bicondylar diameter)] (obs. average bicondylar diameter for femora or for tibiae separately).

Each bone was divided in five distinct 5 cm segments corrected for the articular surface. Each segment was numbered (1 to 5) from the first segment that was marked at 5 cm from the articular surface. The epiphysial segments were not included (Table 1).

The testing units were grouped according to the bone of origin and according to the relative distance from the articular surface.

Cortical layer thickness, rupture load (extraction force for maximal shearing resistance) and shearing tension from the left and right femur and tibia segments were analyzed.

Student's *t* test and Tukey's variance analysis test were employed. A significance level of 5% ($p<0.05$) was chosen for all tests.

RESULTS

Average thickness, rupture load, and shearing tension and respective standard deviation values are shown in Tables 2, 3, and 4 as well as Figs 3, 4, 5, and 6.

Student's *t* test analysis for the three parameters for the respective segments on both sides was significant only for shearing tension in segment one on the left and right femur ($p<0.03$).

Table 1 - Number of testing units per bone segment.

	segment 1	segment 2	segment 3	segment 4	segment 5
right femur	15	21	20	15	3
left femur	14	20	19	12	3
right tibia	17	14	18	19	6
left tibia	16	17	18	17	6

Table 2 - Average thickness values (mm).

	segment 1	segment 2	segment 3	segment 4	segment 5
right femur	3.30±0.67	4.14±5.99	5.99±0.73	6.80±1.05	6.34±1.55
left femur	3.02±0.38	4.25±0.71	6.04±0.82	7.15±0.50	7.70±0.80
right tibia	2.46±0.44	3.09±0.63	3.92±0.82	4.33±0.79	4.42±0.65
left tibia	2.40±0.38	2.99±0.58	3.80±0.81	4.28±0.63	4.09±0.58

Analysis of variance: p<0.0001 (*) for all bones.
Tukey's test: significant difference between segments:
Femur: 1x3, 1x4, 1x5, 2x3, 2x4, 2x5 (both sides) and 3x5 (left side only).
Tibia: 1x3, 1x4, 1x5, 2x4 (both sides) and 2x5 (right side only).

Table 3 - Average rupture load (kgf).

	segment 1	segment 2	segment 3	segment 4	segment 5
right femur	65.33±20.90	140.95±47.63	267.00±69.25	354.60±92.50	350.00±70.83
left femur	73.20±22.40	139.20±55.50	267.40±82.80	383.33±17.42	420.00±31.23
right tibia	41.76±10.74	90.36±32.01	144.72±59.64	166.32±44.62	172.50±45.36
left tibia	43.44±22.19	78.24±36.74	133.33±46.53	166.18±53.90	159.17±26.54

Analysis of variance: p<0.0001 (*) for all bones.
Tukey's test: significant difference between segments:
Femur: 1x3, 1,4, 1x5, 2x4, 2x5 (both sides), 2x3 and 3x5 (left side only).
Tibia: 1x3, 1x4, 1x5, 2x5 (both sides) and 3x4 (right side only).

Table 4 - Shearing tension load (kgf/mm^2).

	segment 1	segment 2	segment 3	segment 4	segment 5
right femur	1.42±0.44	2.38±0.54	3.40±1.07	3.69±0.89	3.91±0.52
left femur	1.70±0.37	2.26±0.65	3.04±0.60	3.41±1.12	3.82±0.24
right tibia	1.23±0.32	2.11±0.55	2.52±0.64	2.70±0.41	2.77±0.63
left tibia	1.25±0.53	1.79±0.68	2.40±0.48	2.70±0.52	2.37±0.95

Analysis of variance: p<0.0001 (*) for all bones.
Tukey's test: significant difference between segments:
Femur: 1,4, 1x5 (both sides), 1x3 (right side only) and 2x5 (left side only).
Tibia: 1x3, 1x4 and 1x5 (both sides).

Table 5 – Comparison with data in the literature.

	Load (Kgf)		Shearing tension (Kgf/mm^2)	
	femur	tibia	femur	tibia
This report	65 - 420	42 - 172	1.5 - 4.0	1.2 - 2.7
Lyon et al.[4]	100 - 158	108 - 170	2.5 – 3.5	2.6 - 3.9
Schatzker et al.[6]			6.17	
Vangsness et al.[8]			4.68	
Koranyi et al.[3]			2.82	

DISCUSSION

The results of this investigation are strictly concerned with the immediate post-operative period when the stability of the montage depends exclusively on mechanical factors. Schatzker et al[6] reported an increase in mechanical resistance to extraction of the screw-bone system in the weeks following implantation.

The application of a relative distance as an indicator of the position of the bone sample was necessary to permit comparison between bones of different lengths. The arbitrary division of the bones included in the analysis into five segments numbered from the metaphysis to the diaphysis permitted the statistical comparison between different bone segments with an adequate number of samples in each segment.

The decision to select the lateral surface of the bone cortex as a source for the bone samples was made because this surface is usually chosen for the site of osteosynthesis procedures with plates and screws.

More specifically, the lateral surface of the femur has an easier surgical access, and the lateral surface of the tibia has adequate muscle coverage.

The variation recorded for the cortical thickness, rupture load, and shearing tension between the segments was statistically significant. It shows that there is a progressive increase in the measures from segment 1 through segment 3. This increase tends to attenuate or stabilize for segments 3 through 5 (Tables 1, 2, and 3 and Figs. 3, 4, 5, and 6).

The right- and left-side segments did not show a statistically significant difference for the measures analyzed, except for the shearing tension on segment 1 of the femur. This difference is possibly due to a minor technical problem in this segment where the thickness of the cortical layer is on the average smaller than two steps of the screw thread.

These data compares with other reports in the literature (Table 5). The values reported by Lyon et al.[4] (108 to 158 kgf) and Schatzker et al.[6] (218 kgf) regarding the rupture load for the femur fall between the values obtained in this investigation (65 to 420 kgf). However, the data of Schatzker et al.[6] were obtained in two cortical layers.

Regarding the tibia rupture load, the values obtained in this investigation (42-172 kgf) encompass the values yielded by Lyon et al.[4] (108 to 170 kgf) measured in single bone cortex.

The femur shearing force range determined in this investigation (1.5 to 4.0 kgf/mm^2) is greater than that reported by Lyon et al.[4] (2.5 to 3.5 kgf/mm^2). Both investigations were performed with a single bone cortex.

Schatzker et al.[6] and Vangsness et al.[8] recorded 6.17 kgf/mm^2 and 4.68kgf/mm^2 respectively for two cortical layers. Yet, Koraniy et al[3] obtained 2.82 kgf/mm^2 for femur shearing tension. The authors recorded 1.2 to 2.7 kgf/mm^2 for tibia shearing, which was lower than the data reported by Lyon et al[4] for a single bone cortex (2.60 to 3.90 kgf/mm^2).

Hughes and Jordan[2] have demonstrated that the shearing tension does not depend on the pilot hole as long as the hole diameter is smaller than the external screw diameter. Shearing tension does not depend on the amount of material between the screw threads either. Shearing tension reflects the intrinsic quality of the material holding the inserted screw.

We showed both an increase in cortex thickness and an increase in resistance to shearing, moving from the metaphysis to the diaphysis.

Regarding weight bearing, the thinness and reduced resistance presented by the cortical metaphyseal bone is counterbalanced by greater bone diameter in this location. The greater diameter of the metaphysis is responsible for a larger inertial momentum of the

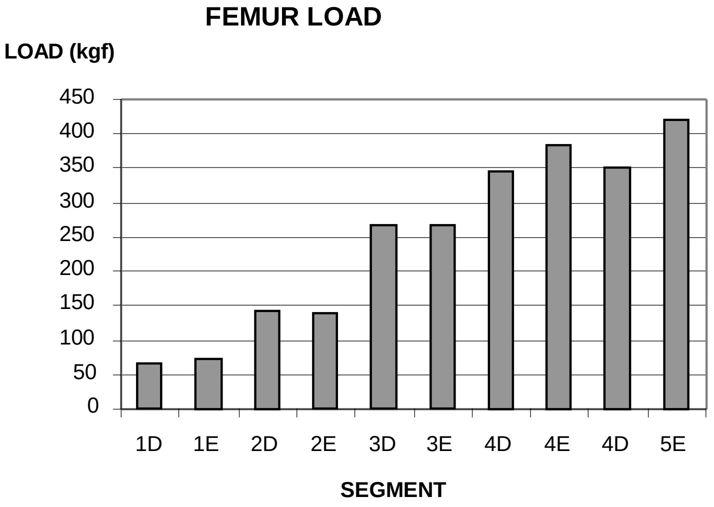

Figure 3 - Rupture load distribution in femur segments.

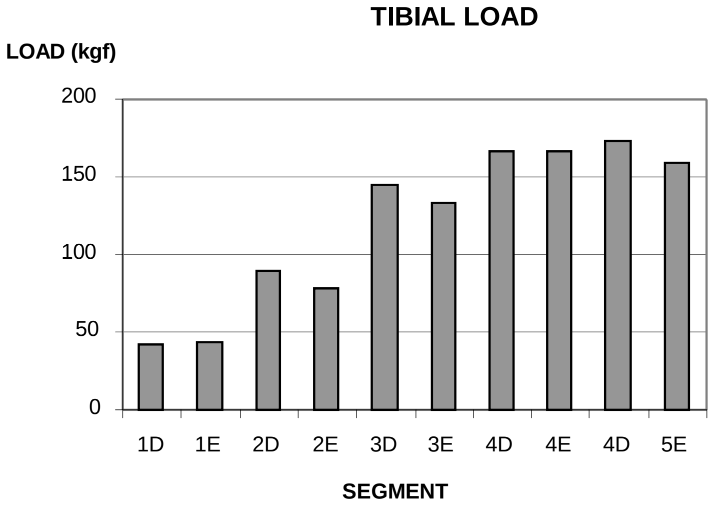

Figure 4 - Rupture load distribution in tibia segments.

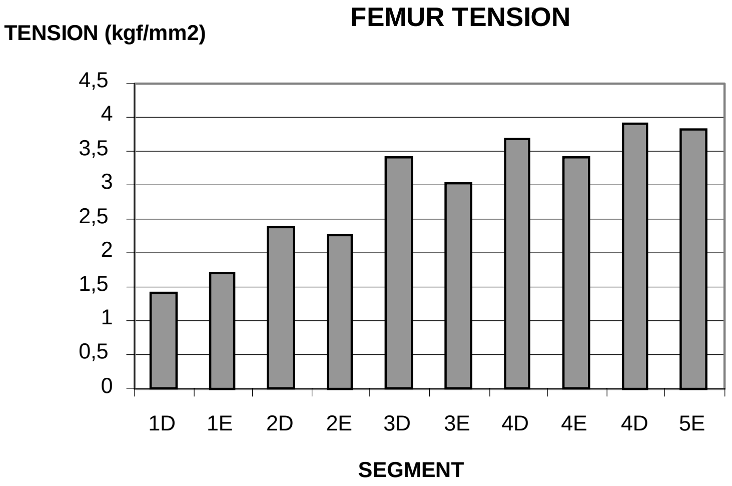

Figure 5 - Shearing tension distribution in femur segments.

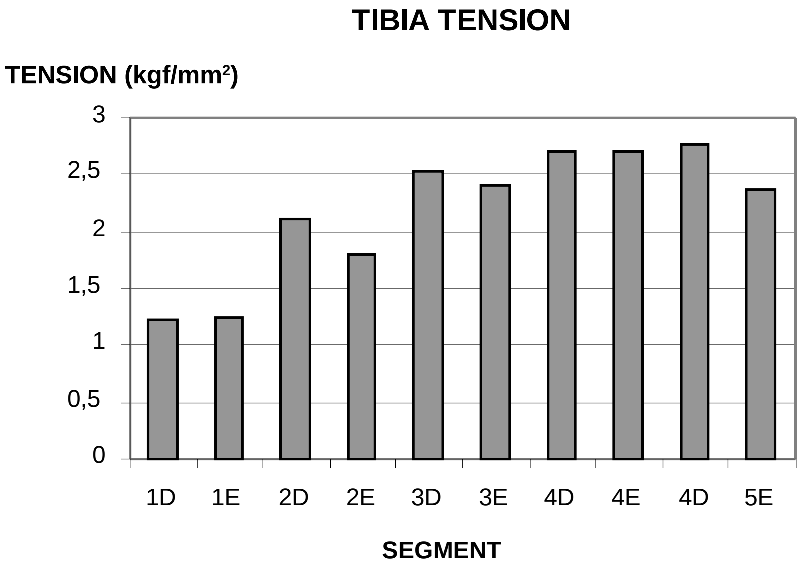

Figure 6 - Shearing tension distribution in tibia segments.

bone. The spongy nature of the epiphyseal and metaphyseal bone segments indicates that weight bearing is distributed in the local trabeculae. As the weight bearing is transferred from the metaphysis to the diaphysis, weight bearing becomes more dependent on the cortical layer, which, in turn, becomes thicker and more resistant. These functional considerations are in keeping with the finding that the closer to the diaphysis, the thicker and more resistant the cortical layer becomes.

CONCLUSION

The cortical layer thickness, rupture load, and shearing tension all progressively increased from the metaphysis to the diaphysis. This progressively increasing pattern corresponds to quantitative and qualitative changes in bone diameter, cortex thickness, and character of the local trabeculae along the femur and tibia.

RESUMO

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BOLLIGER Neto R e col. – Determinação experimental da retenção do parafuso ortopédico em cortex ósseo. **Rev. Hosp. Clín. Fac. Med. S. Paulo 54** (6):181-186, 1999.

Foram retirados corpos de prova cilíndricos de 15 mm de diâmetro da camada cortical da face lateral de 10 pares de fêmures e tíbias oriundos de peças anatômicas. No centro de cada um destes foi feito um orifício de 3,2 mm e nele inserido, a partir da superfície externa, um parafuso cortical de 4,5 mm de diâmetro após rosqueamento com macho. Este conjunto foi submetido a um ensaio mecânico no qual o parafuso foi extraído. A espessura da camada cortical e a carga de ruptura foram medidas e a tensão de cisalhamento foi calculada. Os resultados foram agrupados de acordo com o segmento do osso de onde provinham. Os ensaios mostraram que a retenção cortical do parafuso varia ao longo do osso e que o tecido ósseo da córtex diafisária é tanto quantitativamente quanto qualitativamente mais resistente à extração do parafuso que o tecido metafisário.

DESCRITORES: **Osso e ossos. Biomecânica. Parafusos ósseos. Resistência à tração.**

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