# BIOMECHANICAL STUDY OF THE OSTEOSYNTHESIS STIFFNESS WITH BRIDGING PLATES IN CADAVERIC TIBIAL MODELS

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## ABSTRACT

Objective: To compare the stiffness of three different assemblies of bridging plates with intramedullary locking nails in cadaveric models of tibial fractures type C. Materials and Methods: Twenty cadaveric tibias subjected to type C fractures; fifteen were fixed with the bridging plate technique and divided into three groups, according to the plate size (10, 14 and 18 holes), and five were fixed with intramedullary nail. All the tibias were exposed to similar and progressive loads. Dislocation of both fragments (proximal and distal) was measured on three planes (sagittal, coronal and axial), as the load was increased. Results: tibias fixed with the 18 hole bridging plate have the same biomechanical behavior of tibias fixed with intramedullary locking nails. Conclusions: In type C tibial fractures, there is more mobility at the distal segment on the coronal plane when the fracture is fixed with 14 and 18 holes bridging plates as compared to fractures fixed with non-reamed intramedullary locking nails. Even with this mobility, the relative movements between the fragments at GHB and GP18 seem to be similar.

**Keywords:** Tibial fractures. Bone plates. Internal fixation. Bone nails.

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## INTRODUCTION

Tibial diaphyseal fractures are the most frequent among long bone fractures. It is estimated that around 300,000 new fractures are treated per year in the USA, and around 50,000 in Brazil.[1] The classification used most often in the evaluation of these fractures is that proposed by the AO group, where type A fractures are simple, those of type B present a wedge fracture, and those of type C are complex comminutive fractures.[2] Osteosynthesis by the relative stability principle is indicated in type C fractures, whereas the implant options for obtainment of this principle are external fixation, intramedullary nail and bridging plate. The intramedullary locking nail is considered by many authors to be the method of choice in the definitive treatment of type C diaphyseal fractures of the long bones of the lower limbs. However, there are situations where the use of the nail is limited, such as in diaphyseal fractures with articular extension, fracture traces in the diaphyseal-metaphyseal transition, cutaneous lesions at the point of entrance of the nail, unavailability of radioscopy and restriction of nail use due to the high cost of the implant. In these cases a therapeutic option is the bridging plate. However, there is no definition in literature relating to the plate length and the number of screws to be used in fracture osteosynthesis. Tornkvist et al.[3], in a study on the ratio of the number and position of screws in fracture stabilization, concluded that the force in torsion is dependent on the number of screws and the force in flexion increases with the spacing between screws. Sanders et al.[4], in a biomechanical study with cadaveric ulnas, concluded that the number of screws is less important than the plate length in relation to stiffness in flexion of the model. Stoffel et al.[5] suggest the use of long plates with few screws for the fixation of tibial fractures. In another study on biomechanics, Stoffel et al.[6] arrived at the following recommendations: for fixation of fractures with bridging plate of the lower limb, 2 or 3 screws should be used on each fragment, while for the upper limb this number is 3 or 4; in simple fractures 1 or 2 holes of the plate should be omitted on each side of the fracture; while in fractures with a large comminution area the holes closest to the fracture should be filled. The aim of this study is to compare the stiffness of three different bridging plate assemblies with that of the intramedullary locking nail in cadaveric tibias with type C fracture.

All the authors declare that there is no potential conflict of interest referring to this article.

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## MATERIALS AND METHODS

This study was conducted at the Orthopedics and Traumatology Institute of Hospital das Clínicas da Faculdade de Medicina da Universidade de São Paulo (IOT-HC-FUMUSP), together with the Laboratory of Medical Investigations LIM-41 of HC-FMUSP.

Twenty tibias of random adult cadavers were obtained from the Coroner's Service (SVO) and dissected in such a way as to be devoid of any soft tissue envelope. The length of the tibias ranged from 32.5cm to 39.5cm. These remained frozen at -18ºC in a common horizontal Gafa freezer up to the fixation time, when they were thawed through immersion in saline solution at room temperature for around 2hrs. The tibias were then fixed and the biomechanical assay was carried out within 24 hours.

The tibias were sorted and distributed into four groups with five parts in each one. The groups were divided according to the type of osteosynthesis in intramedullary locking nail (GHB), 10 hole bridging plate (GP10), 14 hole bridging plate (GP14) and 18 hole bridging plate (GP18). A type C diaphyseal fracture of the AO classification was simulated in all the tibias through excision of a fragment of the medial third so that the distal and proximal fragments of the tibias had the same length of 16.25cm and with a distance between the fragments of 2.6 cm. The distances among screws located closest to the focal point of the fracture, called work area, were 200mm, 22.6mm, 87.6mm and 152.6mm, respectively (Figure 1).

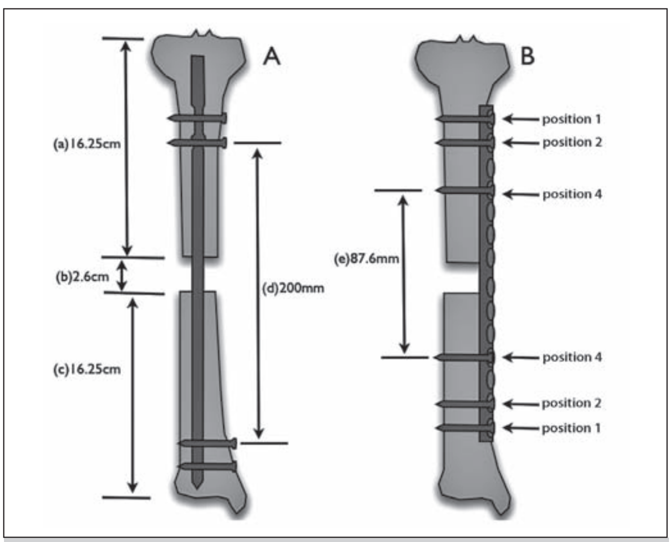


**Figure 1** – *Schematic drawing showing a tibia fixed with intramedullary locking nail (A), and another with 14-hole bridging plate (B). (a): length of proximal fragment of tibia; (b) distance of 2.6 cm to simulate a type C fracture; (c): length of the distal fragment of the tibia; (d): work area of the intramedullary locking nail; (e) work area of the 14-hole bridging plate.*

### Intramedullary Locking Nail Group

The participants used Synthes® model UTN intramedullary locking nails for tibia, made in stainless steel, with a length of 315 mm and diameter of 8 mm.

The nails were introduced through the proximal part of the tibia inside the intramedullary canal, without reaming. The proximal fixation was executed first with two 4.9mm locking screws in the coronal plane, parallel to one another, with one for locking of the static type and the other dynamic. The distance of 2.6 cm was maintained between the proximal and distal segments, and the distal fixation was then performed with the help of radioscopy, also with two parallel locking screws. The orifices for the insertion of the locking screws were made with a 3.2mm drill.

### Bridging Plate Groups

Fifteen straight and narrow 4.5 mm thick Synthes® DCP plates of large fragments made in stainless steel were used, with five 10 hole plates, five with 14 holes and five with 18 holes. The plates were molded in order to maintain the original bone axis and fixed with cortical screws made in steel with a diameter of 4.5 mm, after perforation with a 3.2mm drill and reaming of the orifice.

Each plate was fixed with 3 bicortical screws in the proximal fragment and 3 in the distal fragment, in orifices 1, 2 and 4, that is, first, second and fourth orifices counted from the plate extremities.

Like in the tibias fixed with nails, the distance of 2.6 cm was maintained to simulate a type C fracture.

The distance between the most central screws (positions 4 of the plates) and the focal point of the fracture was 10.0mm, 42.5mm and 75.0mm for the tibias fixed with 10, 14 and 18 hole plates respectively.

### Mechanical Assay

An axial compression assay was conducted on each tibia prepared according to the groups described, by means of a Kratos® model K5002 universal mechanical testing machine, fitted with a 100 kgf load cell and with resolution of 0.1 kgf. The data originating from the machine was sent to the computer by means of a Lynx® model ADS2000 data acquisition system and a computer program designed to record the assay in real time at a rate of 30 acquisitions/second. The assays were carried out at a speed of 5 mm/min.

The tibia was fixed to the testing machine through a set of devices so that the compressive load was applied anteriorly 2.5 cm in relation to the longitudinal axis of the bone.[7]

The distal and proximal portions of the tibia were inserted in two molds with cylindrical cavities then fixed with polymethylmethacrylate (acrylic cement) so that three centimeters of the proximal portion and five centimeters of the distal portion were immersed in the acrylic cement. The proximal mold contained an eccentric pin located 2.5 cm anterior to the tibia axis, and was connected to the load cell through a metallic cylinder. Another metallic cylinder was used to fasten the distal mold to the base of the testing machine.

Compression of 5 kgf was applied on each tibia for accommodation of the system, and after removal of the load, the assay sequences were carried out in a discontinuous manner, applying compressive loads with scheduled stops at the values of 18kgf, 36kgf, 54kgf and 72kgf.

During the assay, the displacements of the bone fragments in the fracture region were measured at each scheduled stop of the machine. The measurements were made by a three-dimensional photogrammetry system (Figure 2), developed in the laboratory.

### Three-Dimensional Photogrammetry Method

The system consists of determining the spatial coordinates, X, Y and Z of any point located inside a volume delimited by a comparator that contains six or more known points. The process is divided into calibration and measurement of the desired point.

The calibration is performed taking two photos of the comparator, by two cameras, in different positions. Using a program developed in the laboratory, it was possible to determine coordinates u and v corresponding to the points of the calibrator evidenced in the two

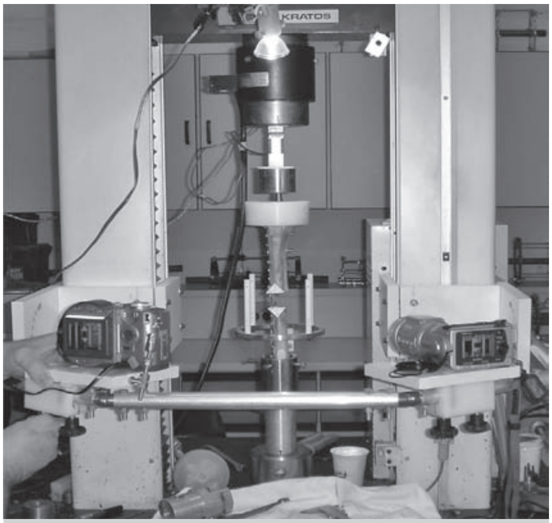


**Figure 2** – *Tibia positioned in the mechanical testing machine with the three-dimensional photogrammetry system.*

photos. Coordinates u and v of each photo are inserted in the DLT (direct linear transformation) method, aiming to obtain a set of equations that relates the projections of the points in the images with the three-dimensional location of the same points in the comparator.[8]

In the measuring process, the points to be measured should be inside the volume occupied by the comparator and photographed by the same cameras previously positioned during the calibration process. The same program described previously allows the localization of coordinates u and v of the points registered in each photo. The transformation of these points into spatial coordinates is performed with the use of the same equations generated in the calibration process.

The comparator consists of four cylindrical bars joined by a metallic ring, with each bar containing two equidistant points of 80 mm, totaling eight points that represent a volume of 800 $cm^3$. Spatial coordinates X, Y and Z of each point are measured in relation to the reference point number one with precision of 0.01 mm.

Two triangular templates containing three points each were used to determine the displacements of the bone fragments. The distances between the three points of each template were measured previously in a Deltronic® profile projector with 20x magnification and equipped with two linear optical sensors with resolution of 0.002 mm. (Figure 3)

The templates were fixed to the bone fragments using two 1.5 mm screws so that points 1, 2, 4 and 6 were all at the same height of the cutting plans of the bone fragments.

The displacements of the upper and lower templates in planes X,Y and Z were calculated from the intersections of the perpendicular bisectors between the three points of each template. In relation to the anatomical planes, the lateromedial displacements were measured in the sagittal plane (plane XZ), anteroposterior in the coronal plane (axis YZ) and superoinferior in the longitudinal axis (axis Z).

### Parameters Analyzed

The displacements of the upper and lower bone fragments were recorded in relation to the initial positions of the templates (zero load) in keeping with the increases of the compressive load of 18 kgf, 36 kgf, 54 kgf and 72 kgf. The lateromedial and anteroposterior displacements were expressed in modules, with the aim of identifying the amplitude of movement, but not the displacement direction.

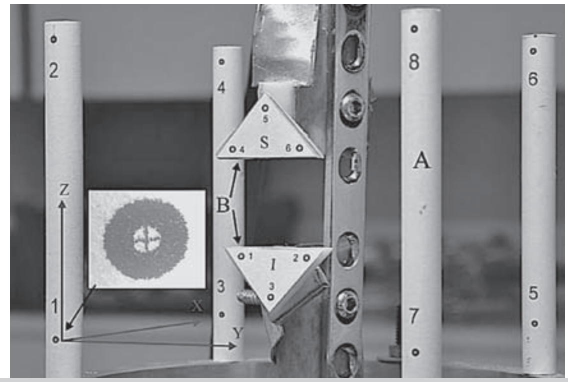


**Figure 3** – *Tibia and plate positioned inside the comparator (A), evidencing the triangular templates (B) fixed to the upper and lower bone fragments. The Cartesian system had its origin at point number one (in detail).*

The distance between the midpoints of the upper and lower template was determined by the Pythagoric method and was related with the load application sequence mentioned previously.

The measurements obtained were as follows:

1. Measurements of the displacements in the sagittal plane (plane X):
   – displacement of the upper marker in relation to its position without load (D-SUPX)
   – displacement of the lower marker in relation to its position without load (D-INFX)
2. Measurements of the displacements in the coronal plane (plane Y):
   – displacement of the upper marker in relation to its position without load (D-SUPY)
   – displacement of the lower marker in relation to its position without load (D-INFY)
3. Measurements of the displacements in the craniocaudal axis (axis Z):
   – displacement of the upper marker in relation to its position without load (D-SUPZ)
   – displacement of the lower marker in relation to its position without load (D-INFZ)
4. Measurement of the distance between the upper and lower markers:
   – distance between the upper and lower markers (DI-SUP-INF)

The General Linear Model with repeated measurements was used to evaluate for statistical significance of results. This makes it possible to test whether there is at least 01 (one) difference among the mean values of the assays through the Variance Analysis (ANOVA).

The Post Hoc analysis was conducted using Scheffé's method for multiple comparisons. A significance level of 5% was considered for both cases.

## RESULTS

The graphs represented in Figures 4 to 10 show the mean value of displacements measured in the 4 groups (GHB, GP10, GP14 and GP18) with application of loads of 18 kgf, 36 kgf, 54 kgf and 72 kgf, in the different planes and axes of the space (X, Y, Z and total).

The Variance Analysis (ANOVA) was used to compare all the results obtained in the assays, that is, all the displacements (sagittal, coronal and axial planes and total) of GHB, GP10, GP14 and GP18, as the applied load evolved from 0kgf to 72kgf, to find the significant

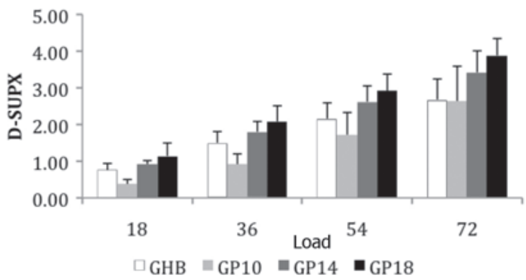


**Figure 4** – *Mean values of the displacements in the sagittal plane of the upper marker (D-SUPX) in GHB, GP10, GP14 and GP18 measured with the application of loads of 18 kgf, 36 kgf, 54 kgf and 72 kgf.*

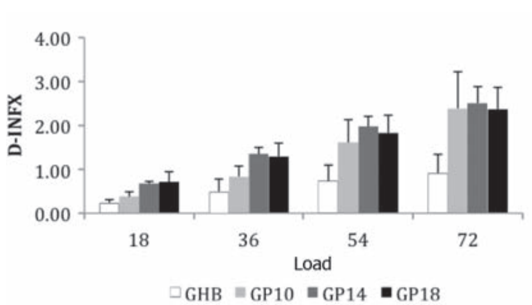


**Figure 5** – *Mean values of the displacements in the sagittal plane of the lower marker (D-INFX) in GHB, GP10, GP14 and GP18 measured with the application of loads of 18 kgf, 36 kgf, 54 kgf and 72 kgf.*

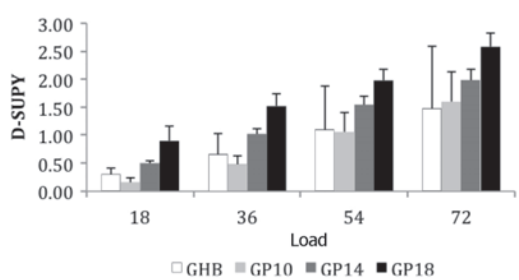


**Figure 6** – *Mean values of the displacements in the coronal plane of the upper marker (D-SUPY) in GHB, GP10, GP14 and GP18 measured with the application of loads of 18 kgf, 36 kgf, 54 kgf and 72 kgf.*

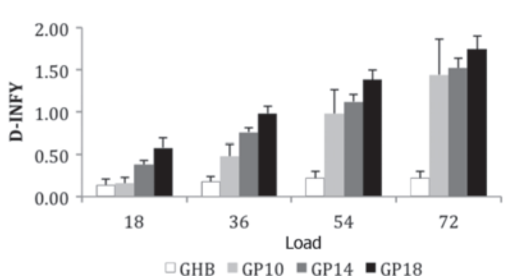


**Figure 7** – *Mean values of the displacements in the coronal plane of the lower marker (D-INFY) in GHB, GP10, GP14 and GP18 measured with the application of loads of 18 kgf, 36 kgf, 54 kgf and 72 kgf.*

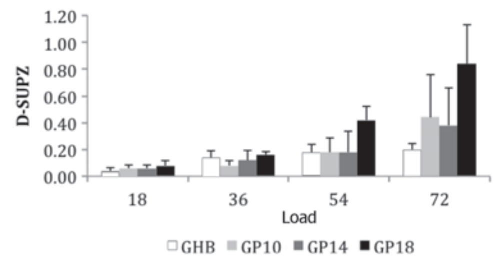


**Figure 8** – *Mean values of the displacements in the craniocaudal axis of the upper marker (D-SUPZ) in GHB, GP10, GP14 and GP18 measured with the application of loads of 18 kgf, 36 kgf, 54 kgf and 72 kgf.*

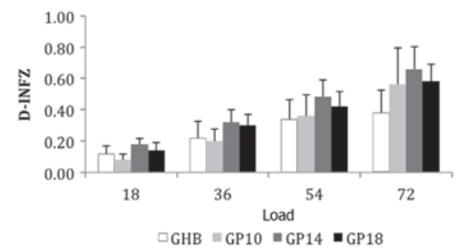


**Figure 9** – *Mean values of the displacements in the craniocaudal axis of the lower marker (D-INFZ) in GHB, GP10, GP14 and GP18 measured with the application of loads of 18 kgf, 36 kgf, 54 kgf and 72 kgf.*

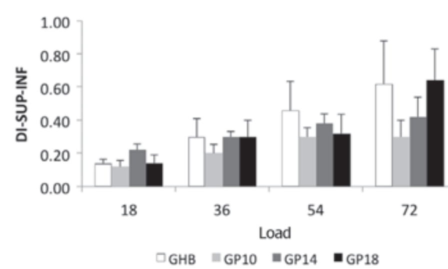


**Figure 10** – *Mean values of the distances (DI-SUP-INF) in GHB, GP10, GP14 and GP18 measured with the application of loads of 18 kgf, 36 kgf, 54 kgf and 72 kgf.*

differences. A significant difference was found in the analyses of the mean values of D-INFY. (Table 1)

In the comparison between the displacements found in GHB with GP10, GP14 and GP18 there were no significant differences in any of the displacements tested, except in D-INFY, where significantly higher values were found in GP14 and GP18. (Table 2)

**Table 1** – *Variance Analysis of all the results obtained in the assays (ANOVA).*

| Displacements | p |
|---|---|
| D-SUPX | 0.283 |
| D-INFX | 0.147 |
| D-SUPY | 0.250 |
| D-INFY | 0.001* |
| D-SUPZ | 0.403 |
| D-INFZ | 0.748 |
| DI-SUP-INF | 0.663 |

**Table 2** – *Comparison between the D-INFY found in GHB with the GP10, GP14 and GP18 (POST HOC Analysis – Scheffé's Method for Multiple Comparisons).*

| Groups compared | | Mean differences | p Value | Confidence Interval (95%) | |
|---|---|---|---|---|---|
| | | | | Lower | Upper |
| GHB | GP10 | -0.575 | 0.052 | -1.153 | 3.460 |
| GHB | GP14 | -0.755 | 0.009* | -1.333 | -0.177 |
| GHB | GP18 | -0.980 | 0.001* | -1.558 | -0.402 |

## DISCUSSION

Femoral and tibial diaphyseal fractures are treated with considerable efficiency by means of osteosynthesis with intramedullary locking nail. The use of this kind of implant has allowed high consolidation indexes with low rates of complications. The rate of infection was about 2% and that of non-union was less than 2% in the majority of the series.[9-18]

In spite of this, the bridging plate continues to be an excellent treatment option, particularly at public healthcare centers, where the high cost of more modern intramedullary locking nails and the greater difficulty in access to these implants hinder their indiscriminate use.

Now in humeral diaphyseal fractures, where the intramedullary locking nails do not show clear superiority in relation to the plates used conventionally by the principle of absolute stability, the use of bridging plates has been occurring more and more frequently, and with good results.[19]

The work area of the bridging plate, defined as the region between the screws closest to the focal point of the fracture, defines how much mobility will exist among the bone fragments, and unlike the work area of a intramedullary locking nail, can be altered by the orthopedic surgeon. When we increase the distance between these screws, either by altering the distribution of screws in the same plate, or using a longer plate, we will be increasing the work area and, consequently, the movement among the bone fragments at the focal point of the fracture.

How much movement is ideal for the consolidation of a fracture by the principle of relative stability? Unfortunately this question is impossible to answer, as several other factors influence the consolidation process. However, if we consider that the mobility brought about by the intramedullary locking nail allows successful consolidation in most diaphyseal fractures, a bridging plate with similar stiffness might be the best option. Intramedullary locking nails have a large work area, as the locking screws are situated at the extremities of the nail. Precisely due to this fact, the tendency in clinical practice is for the use of long plates with central screws at a significant distance from one another. In this study we attempted to identify which plate length offers stiffness similar to that of the intramedullary locking nail in tibia fractures.

The analysis of the graphs (Figures 1 to 6) referring to the displacements occurring in the upper and lower segments of the tibias with application of progressive loads shows that there was more movement of the markers in the tibias fixed with plates, in relation to the GHB, especially in GP18. However, this difference appeared statistically significant only in the displacements of the lower segment in the coronal plane (Tables 1 and 2).

This greater movement, and consequently lesser stiffness of osteosynthesis with plates, suggests that assemblies with narrow bridging plates on the anteromedial side of human tibias provide a higher degree of mobility at the focal point of type C fractures than intramedullary locking nails. In other words, even assemblies with short plates (10 holes) are less stiff than those with locked nails. Figure 7 shows the distances between upper and lower markers with the application of loads, and it can be noted that the distances in GHB and GP18 are similar, both greater than those found in GP10 and GP14. These distances show the relative movement between one fragment and another. A possible interpretation for this finding is that although the fracture fragments move more in the groups fixed with plates, this movement occurs in the same direction, while in the tibias fixed with intramedullary locking nail the movements occur in different directions, so that the relative displacements among the fragments are similar in GHB and GP18. Another possible interpretation is that these differences are only artifacts resulting from the small number of tibias studied, as there was no statistically significant difference in this analysis.

Our impression after the conclusion of this work is that the 18 hole bridging plates present a biomechanical behavior similar to that of the intramedullary locking nail.

## CONCLUSIONS

In type C fractures in human cadaveric tibias there is greater mobility of the lower bone segment in the coronal plane, when the fracture is fixed with 14 and 18 hole bridging plates than when fixed with intramedullary locking nail without reaming. Despite this greater mobility, the relative movements among the fracture fragments in GHB and GP18 tend to resemble one another.

## REFERENCES


1. Ferreira JC. Fraturas da diáfise dos ossos da perna. Rev Bras Ortop. 2000;35:375-83.
2. Müller ME, Allgöwer M, Schneider R, Willenegger H. Manual de Osteossíntese. 3a ed. Tradução de Jacques Vissoky. São Paulo: Manole; 1993. p.45-58.
3. Tornkvist H, Hearn TC, Schatzker J. The strength of plate fixation in relation to the number and spacing of bone screws. J Orthop Trauma. 1996;10:204-8.
4. Sanders R, Hidukewych GJ, Milne T, Dennis J, Latta LL. Minimal versus maximal plate fixation techniques of the ulna: the biomechanical effect of number of screws and plate length. J Orthop Trauma. 2002;16:166-71.
5. Stoffel K, Stachowlak G, Forster T, Gachter A, Kuster M. Oblique screws at the plate ends increase the fixation strength in synthetic bone test medium. J Orthop Trauma. 2004;18:611-6.
6. Stoffel K, Dieter U, Stachowiak G. Gachter A, Kuster MS. Biomechanical testing of the LCP – how can stability in locked fixators be controlled? Injury. 2003;34(Suppl 2):11-9.
7. Toledo CS. Estudo mecânico do fixador externo de Rossi [tese]. São Paulo: Faculdade de Medicina da Universidade de São Paulo;1989.
8. David AC. Um novo método fotogramétrico adequado à análise biomecânica. Comparação com o método DLT (Transformação Linear Direta) [dissertação]. Santa Maria: Universidade Federal de Santa Maria – RS; 1992.
9. Klemm KW, Borner M. Interlocking nailing of complex fractures of the femur and tibia. Clin Orthop Relat Res. 1986;(212):89-100.
10. Henley MB, Chapman JR, Agel J, Harvey EJ, Whorton AM, Swiontkowski MF. Treatment of type II, IIIa and IIIb open fractures of the tibial shaft: a prospective comparison of unreamed interlocking intramedullary nails and half-pin external fixators. J Orthop Trauma.1998;12:1-7.
11. Court-Brown CM, Christie J, McQueen MM. Closed intramedullary tibial nailing. Its use in closed and type I open fractures. J Bone Joint Surg Br. 1990;72:605-11.
12. Alho A, Ekeland A, Strømsøe K, Benterud JG. Non-union of tibial shaft fractures treated with locked intramedullary nailing without bone grafting. J Trauma. 1993;34:62-7.
13. Hooper GJ, Keddell RG, Penny ID. Conservative management or closed nailing for tibial shaft fractures. A randomised prospective trial. J Bone Joint Surg Br. 1991;73:83-5.
14. Habernek H, Walch G, Dengg C. Cerclage for torsional fractures of the tibia. J Bone Joint Surg Br. 1989;71:311-3.
15. Winquist RA, Hansen ST Jr. Comminuted fractures of the femoral shaft treated by intramedullary nailing. Orthop Clin North Am. 1980;11:633–47.
16. Winquist RA, Hansen ST Jr, Clawson DK. Closed intramedullary nailing of femoral fractures. A report of five hundred and twenty cases. J Bone Joint Surg Am. 1984;66:529-39.
17. Winquist RA, Hansen ST. Segmental fractures of the femur treated by closed intramedullary nailing. J Bone Joint Surg Am. 1978;60:934-9.
18. Wolinsky PR, McCarty E, Shyr Y, Johnson K. Reamed intramedullary nailing of the femur: 551 cases. J Trauma. 1999;46:392-9.
19. Livani B, Belangero WD. Bridging plate osteosynthesis of humeral shaft fractures. Injury. 2004;35:578-95.