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Original article

Experimental trial on surgical treatment for transverse fractures of the proximal phalanx: technique using intramedullary conical compression screw versus lateral compression plate[☆]

Daniel Schneider Ibanez[*], *Fabio Lucas Rodrigues*, *Rafael Salmeron Salviani*, *Fernando Augusto Reginatto Roberto*, *Jose Roberto Pengo Junior*, *Marcio Aurelio Aita*

Laboratório de Ensaios Mecânicos e Metalográficos (LEMM), Jaú, SP, Brazil

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ABSTRACT

Objective: To compare the mechanical parameters between two methods for stabilization through compression: 1.5 mm axial compression plate versus conical compression screw used as an intramedullary tutor.

Methods: Polyurethane models (Sawbone®) that simulated transverse fractures of the proximal phalanx were used. The models were divided into three groups: lateral plate, conical screw and no implant.

Results: Greater force was needed to result in fatigue in the synthesis using an intramedullary plate. Thus, this model was proven to be mechanically superior to the model with the lateral plate.

Conclusion: Stabilization using the Acutrak® screw for treating fractures in the model used in this trial presents mechanical results that are statistically significantly superior to those from the axial compression technique using the lateral plate (Aptus Hand®).

Ensaio experimental para tratamento cirúrgico das fraturas transversas da falange proximal – Técnica com parafuso intramedular cônico de compressão versus placa de compressão lateral

RESUMO

Palavras-chave:
Fixação óssea
Fixação interna de fraturas

Objetivo: Comparar os parâmetros mecânicos entre dois métodos de estabilização por compressão: placa de compressão axial de 1,5 mm com o parafuso cônico de compressão usado como tutor intramedular.

[☆] Work developed in the Laboratório de Ensaios Mecânicos e Metalográficos (LEMM), Jaú, SP, Brazil.

[*] *Corresponding author.*
E-mail: drdanielsi@hotmail.com (D.S. Ibanez).

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Traumatismos da mão
Traumatismos dos dedos

Métodos: Foram usados modelos de poliuretano (Sawbone®) que simulam a fratura da falange proximal transversa, divididos em três grupos (placa lateral, parafuso cônico, sem implante).

Resultados: Há necessidade de uma maior força para resultar na fadiga da síntese com parafuso intramedular. Comprova-se, assim, a supremacia mecânica desse sobre o modelo com a placa lateral.

Conclusão: A estabilização com o parafuso Acutrak®, no tratamento das fraturas no modelo adotado neste ensaio, apresenta resultados mecânicos superiores e estatisticamente significativos em comparação com a técnica de compressão axial com o uso da placa lateral (Aptus Hand ®).

Introduction

Fracture of the phalanges are frequent injuries and account for 6% of all fractures.[1,2] The proximal phalanx is fractured more frequently than the middle or distal phalanges.[3,4]

Indications for surgical treatment for these fractures need to take into consideration the type of fracture line, the displacement between the fragment and the difficulty in maintaining closed reduction of the fracture.[3] The aim of surgical treatment is to restore the anatomy and function of the affected finger.[4,5]

The techniques that have been described range from seeking relative stability to the principle of absolute stability. A combination of methods is sometimes necessary,[6] and this depends on the nature of the fracture line, the availability of implants and the surgeon's preference.

Among the surgical complications, the following can be highlighted: joint stiffness, adherence and/or tearing of the extensor tendon,[1] functional loss of the finger[2] or, additionally, skewed consolidation, pseudarthrosis and osteomyelitis.[5–7]

These complications are often caused by poor knowledge of the biomechanics of this organ; an unfounded belief that all fractures of the hand can be resolved through conservative treatment; or poor cooperation from the patient.[8]

In seeking to minimize these complications, Mantovanni et al.[9] described lateral positioning of the plate in which the extensor tendon was left untouched so as to avoid tendon adherence and joint stiffness. Another option would be to use the principle of an intramedullary internal tutor,[10,11] such as a conical compression screw (Acutrak®), to be placed percutaneously. We describe this novel technique in the present study.

The objective of this study was to compare the mechanical parameters of two methods of stabilization through compression: a 1.5 mm axial compression plate versus a conical compression screw used as an intramedullary tutor. Both of these methods were used on fractures of the diaphysis of the proximal phalanx that followed a transverse line.

Methods

This study was conducted in the Mechanical and Metallographic Testing Laboratory (LEMM), in the city of Jaú, state of São Paulo, Brazil, in May 2012. This laboratory has been certified by INMETRO.

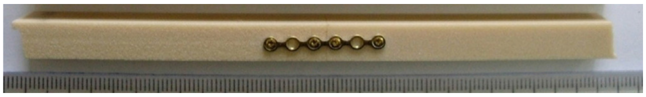


Fig. 1 – Group I model before the mechanical test.

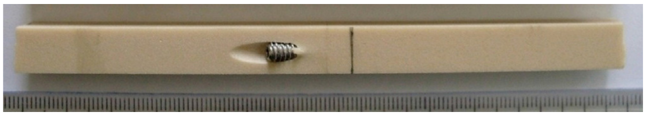


Fig. 2 – Group II model before the mechanical test.

Fifteen polyurethane models simulating the proximal phalanx (Sawbone®), of dimensions 10 mm × 8 mm × 60 mm and density 40 pounds per cubic foot (lb/ft^3) were used. Simple transverse fractures with a single line at an inclination of less than 30° were made.[12]

These models were divided into three groups: five models for each group with synthesis material (groups I and II); and three models for a group without synthesis material (group III).

Group I – with a 1.5 mm compression plate and four cortical screws (Aptus Hand®), placed in the lateral region of the model (Fig. 1).
Group II – one conical compression screw (Acutrak®) of standard type, positioned intramedullarily (Fig. 2).
Group III – models of the phalanx without an implant and without a fracture (Fig. 3).

Placement technique for the lateral plate in the polyurethane model (Fig. 1):

Placement of 1.5 mm plate positioned laterally in the model and, after reduction, placement of four bicortical screws (two

Fig. 3 – Group III model before the mechanical test.

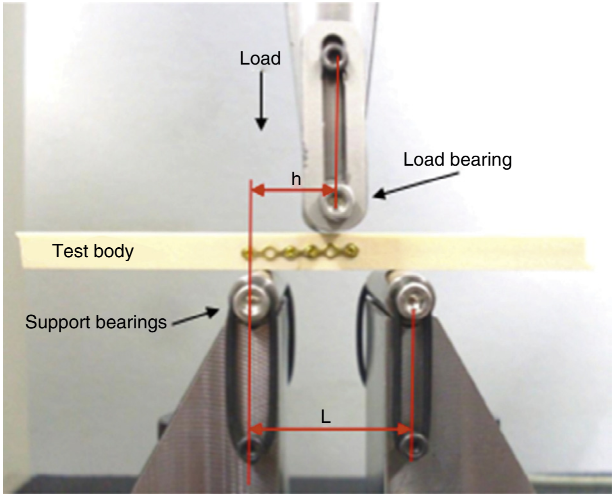


Fig. 4 – Illustrative schematic photo of the flexion test with load-bearing at three points: distance *L*: 40 mm; distance *h*: 15 mm; force applied: 5 mm.

distally and two proximally to the fracture focus) that promote compression axially to the fracture line.

Placement technique for the intramedullary conical compression screw in the polyurethane model (Fig. 2):

Reduction of the fracture in the polyurethane model and passage of the guidewire from the upper face towards the lower face, across the fracture. This is followed by measurement of the size of the implant, drilling of an opening in both cortices and installation of a conical compression screw just below the upper surface in the region proximal to the fracture and adjacent to the distal lower surface of this model.

Application of the mechanical test in the polyurethane models: flexion test at three support points (Fig. 4).

The polyurethane models (test bodies) were placed in a machine (EMIC apparatus, model DL10000) with three contact points: one load bearing and two support bearings. In this manner, the load was applied so as to generate a constantly increasing flexion force until the synthesis material reached fatigue.

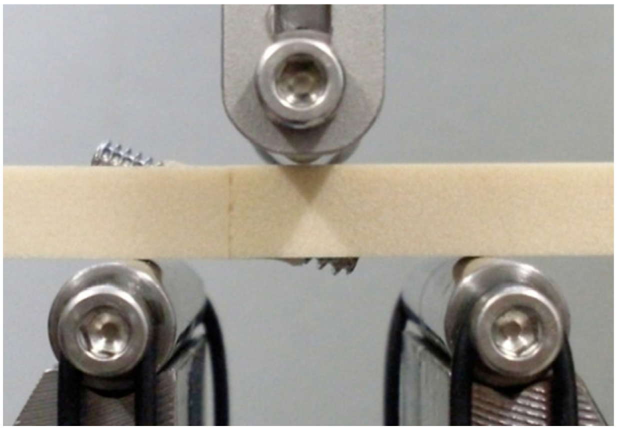
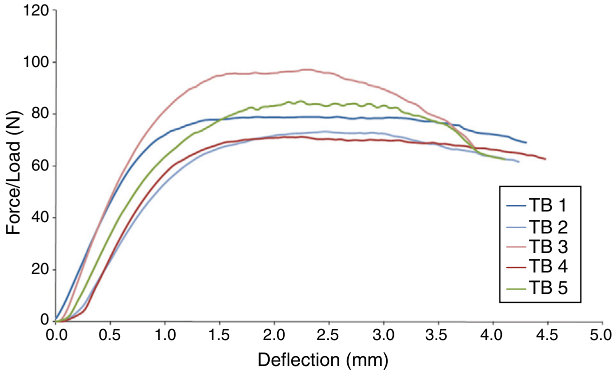


Fig. 5 – Illustrative detailed schematic photo of the flexion test with load-bearing at three points: group II.



Source: Mechanical and metallographic testing laboratory (LEMM)

Fig. 6 – Flexion test curves, with load-bearing at three points, for group I.

Group I – force applied from above to below, with the compression plate positioned laterally.

Group II – force applied from above to below, with the compression screw also placed from above to below, inclined according to the transverse fracture line (Fig. 5).

Group III – force applied from above to below, on the entire test body.

In all the groups evaluated, the distance *L* between the support bearings was the same. In groups I and II, the flexion force applied by the load bearing was kept constant at a distance *h* of 15 mm from the beginning of the synthesis and at 5 mm from the fracture line.

All the data were sent for statistical analysis. The Kruskal–Wallis test was used and the significance level was taken to be 5% (0.050). The Statistical Package for the Social Sciences (SPSS) software, version 21.0, was used to aid in obtaining the results.

The Kruskal–Wallis test was applied to ascertain the possible differences between the three groups, compared simultaneously, for the variables of interest.

Results

In group I (lateral compression plate), the mean maximum flexion force withstood was 81.23 N, with a range from 97.13 to 73.35 N. The mean rigidity under flexion was 90.80 N, with a range from 116 to 70 N (Table 1 and Figs. 6 and 7).

Group II (intramedullary conical compression screw) withstood a mean maximum flexion force of 320.40 N, with a range from 360.08 to 278.85 N. The mean stiffness under flexion was 427.48 N, with a range from 455 N to 385 N (Table 2 and Figs. 8 and 9).

Group III (entire test body) withstood a mean maximum flexion force of 537.50 N, with a range from 545.61 to 528.68 N. The mean stiffness under flexion was 492 N, with a range from 499 N to 480 N (Table 3 and Fig. 10).

Description and comparison of the variables of interest between the three groups studied (Table 4).

The aim was to demonstrate the mean force needed to failure of the reduction that had been achieved using the

Table 1 – Results obtained from flexion test for group I.

Item	K (N/mm)	EI_e (N m^2)	Q (mm)	P (N)	R (N m)	F_{max} (N)
1	96.0	0.05	0.03	54	0.41	79.05
2	70.0	0.04		47	0.35	73.35
3	116.0	0.07		52	0.39	97.13
4	86.0	0.05		47	0.35	71.36
5	86.0	0.05		49	0.37	85.05
Mean	90.8	0.052	0.030	49.8	0.4	81.2
Standard deviation	16.89	0.01		3.11	0.02	10.39

Source: Mechanical and Metallographic Testing Laboratory (LEMM).
K, rigidity under flexion; EI_e, structural rigidity under flexion; *P*, plastic flow load; *R*, moment of flow (resistance to flexion); *q*, displacement at 0.2% of the distance between the external and internal bearings; F_{max}, maximum test force.

Table 2 – Results obtained from flexion test for group II.

Sample	K (N/mm)	EI_e (N m^2)	q (mm)	P (N)	R (N m)	F_{max} (N)
1	434.0	0.24	0.03	250	1.88	360.08
2	455.0	0.26		265	1.99	328.09
3	467.0	0.26		320	2.40	342.55
4	398.0	0.22		250	1.88	278.85
5	385.0	0.22		190	1.43	292.45
Mean	427.8	0.2	0.03	255.0	1.9	320.4
Standard deviation	35.48	0.02		46.37	0.35	34.03

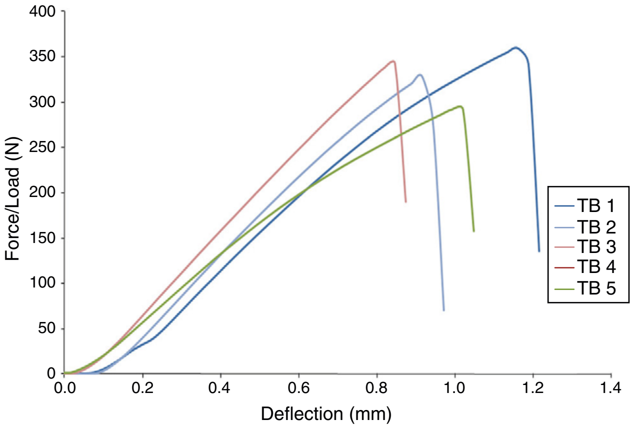
Source: Mechanical and Metallographic Testing Laboratory (LEMM).
K, rigidity under flexion; EI_e, structural rigidity under flexion; *P*, plastic flow load; *R*, moment of flow (resistance to flexion); *q*, displacement at 0.2% of the distance between the external and internal bearings; F_{max}, maximum test force.

Table 3 – Results obtained from flexion test for group III.

Sample	K (N/mm)	EI_e (N m^2)	q (mm)	P (N)	R (N m)	F_{max} (N)
1	480.0	0.27	0.030	430	3.23	528.68
2	499.0	0.28	0.030	420	3.15	545.61
3	497.0	0.28	0.030	410	3.08	538.12
Mean	492.0	0.3	0.030	420.0	3.2	537.5
Standard deviation	10.44	0.01	0.030	10.00	0.08	8.48

Source: Mechanical and Metallographic Testing Laboratory (LEMM)
K, rigidity under flexion; EI_e, structural rigidity under flexion; *P*, plastic flow load; *R*, moment of flow (resistance to flexion); *q*, displacement at 0.2% of the distance between the external and internal bearings; F_{max}, maximum test force.

Fig. 7 – Illustrative photo of group I after the mechanical test.



Source: Mechanical and metallographic testing laboratory (LEMM)

Fig. 8 – Flexion test curves, with load-bearing at three points, for group II.

Table 4 – Application of Kruskal–Wallis test.

Variable	Group	N	Mean	Standard deviation	Minimum	Maximum	P 25	Percentile 50 (median)	P 75	Significance (*p*)
K (N/m)	I	5	90.80	16.89	70.00	116.00	86.00	86.00	96.00	0. 005
	II	5	427.80	35.48	385.00	467.00	398.00	434.00	455.00	
	III	3	492.00	10.44	480.00	499.00	488.50	497.00	498.00	
	Total	13	313.00	186.03	70.00	499.00	96.00	398.00	467.00	
El_e (N m^2)	I	5	0.05	0.01	0.04	0.07	0.05	0.05	0.05	0.005
	II	5	0.24	0.02	0.22	0.26	0.22	0.24	0.26	
	III	3	0.28	0.01	0.27	0.28	0.28	0.28	0.28	
	Total	13	0.18	0.10	0.04	0.28	0.05	0.22	0.26	
q (mm)	I	5	0.03	0.00	0.03	0.03	0.03	0.03	0.03	> 0.999
	II	5	0.03	0.00	0.03	0.03	0.03	0.03	0.03	
	III	3	0.03	0.00	0.03	0.03	0.03	0.03	0.03	
	Total	13	0.03	0.00	0.03	0.03	0.03	0.03	0.03	
P (N)	I	5	49.80	3.11	47.00	54.00	47.00	49.00	52.00	0. 005
	II	5	255.00	46.37	190.00	320.00	250.00	250.00	265.00	
	III	3	420.00	10.00	410.00	430.00	415.00	420.00	425.00	
	Total	13	214.15	152.58	47.00	430.00	52.00	250.00	320.00	
R (N m)	I	5	0.37	0.03	0.35	0.41	0.35	0.37	0.39	0.005
	II	5	1.92	0.35	1.43	2.40	1.88	1.88	1.99	
	III	3	3.09	0.06	3.03	3.15	3.06	3.08	3.12	
	Total	13	1.59	1.12	0.35	3.15	0.39	1.88	2.40	
F_{max} (N)	I	5	81.19	10.39	71.36	97.13	73.35	79.05	85.05	0.005
	II	5	320.40	34.03	278.85	360.08	292.45	328.09	342.55	
	III	3	537.47	8.48	528.68	545.61	533.40	538.12	541.87	
	Total	13	278.49	184.81	71.36	545.61	85.05	292.45	360.08	

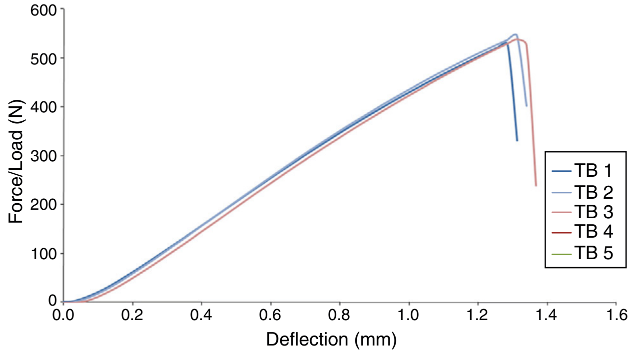
K, rigidity under flexion; El_e, structural rigidity under flexion; *P*, plastic flow load; *R*, moment of flow (resistance to flexion); *q*, displacement at 0.2% of the distance between the external and internal bearings; F_{max}, maximum test force.

synthesis materials (Tables 1 and 2) and fracturing of the test body in group III (Table 3).

The study described here did not present any statistically significant differences in comparing the different models simultaneously and within each group. For this reason, the Mann–Whitney test was applied (Table 5) to identify which groups differed from the others, when compared as pairs.

With the exception of the variable *q* (mm), which remained constant in the three groups, it can be stated that real differences between the groups were present in relation to the other variables of interest.

Fig. 9 – Illustrative photo of group II after the mechanical test.



Source: Mechanical and metallographic testing laboratory (LEMM)

Fig. 10 – Flexion test curves, with load-bearing at three points, for group III.

Table 5 – Application of Mann–Whitney test.

Variable	Pair of groups		
	I vs. II	I vs. III	II vs. III
K (N/m)	0.009	0.024	0.025
El_e (N m^2)	0.008	0.021	0.023
P (N)	0.009	0.024	0.024
R (N m)	0.009	0.024	0.024
F_{max} (N)	0.009	0.025	0.025

Discussion

Fractures of the proximal phalanx are most prevalent among males between the ages of 10 and 40 years. They are usually treated as insignificant injuries, but this results in functional limitation[4] in an economically important population.

Evolution in treatments for fractures of the proximal phalanx is a necessity in our setting, given that the incidence of this fracture has been increasing exponentially and the published results from the established methods are unconvincing.[10] The ideal, in seeking to diminish the postoperative complications, is to combine less invasive techniques with better implant stability, in order to enable early mobilization of the fractured finger.

The new design of locked plates and specifically those of 1.5 mm with a thickness of 2 mm, along with the accompanying instruments (precise guides and tweezers for performing reduction), facilitates the intraoperative procedure.

The use of an Acutrak® conical compression screw (which was designed for treating fractures of the scaphoid), described for the first time in this study, shows the possibility of applying this to fractures of the proximal phalanx with the stability that is necessary for good postoperative recovery. However, for this to be undertaken, mechanical proof that the synthesis would withstand the loading needed during the rehabilitation, and would not impair recovery or bring any harm to the patient, was required. This reason encouraged us to conduct the present study.

Neither the percutaneous approach using the Acutrak® screw in the dorsal region of the finger (as an internal tutor) nor the placement of a lateral plate (using the principle of axial compression) reached the extensor tendon, and adherence of the tendon to the implant was avoided. There was also less risk of joint stiffness, since the hypothesis was that these methods would be sufficiently stable to enable metacarpophalangeal and interphalangeal joint mobility during the immediate postoperative period.

We decided to use a synthetic bone model, rather than an animal phalanx (such as from a pig), because the density in the model would be a constant. This minimized the bias relating to variations in bone density and concentrated the testing on the implants. We standardized on a simple transverse fracture line since this is the best line for obtaining axial compression of the fragments, given that we were going to test techniques that applied compression.

In making horizontal comparisons of the mechanical results between the groups, it was observed that there was a statistically significant difference between groups I and II. Thus, greater force was needed to reach fatigue of the synthesis material consisting of an intramedullary screw. It was therefore shown that this material was mechanically superior to the model with the lateral plate.

Since the mean maximum force in group III (Fig. 3) was 167.8% greater than that of group I and 662.9% greater than that of group II, this shows that the test machine (Fig. 1) did not influence the fracture, but only the implants. The comparative mechanical test performed in the present study was therefore certified.

The results obtained from this study encourage us to proceed further in these investigations, now in a clinical manner. In addition to the mechanical advantage of conical screws, they are applied percutaneously and this may avoid complications relating to the surgical access that is necessary in osteosynthesis using a plate.

Conclusion

Stabilization using Acutrak® screws, in treating the fractures in the model used in this trial, presents mechanical results that are statistically significantly superior to those from the axial compression technique using a lateral plate (Aptus Hand®).

Conflicts of interest

The authors declare no conflicts of interest.

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