Mechanical Analysis after Proximal Femoral Reinforcement with Polymethylmethacrylate in Alternated Double Holes*

Análise mecânica após reforço femoral proximal com polimetilmetacrilato em orifícios duplos alternados

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Abstract

Objective To evaluate, through a biomechanical assay, the maximum load, energy, and displacement necessary for the occurrence of fractures in synthetic models of femurs after the removal of cannulated screws and the performance of a reinforcement technique with polymethylmethacrylate (PMMA) in different combined positions.

Methods In total, 25 synthetic bones were used, and they were divided into 4 groups: the control group (CG), with 10 models without perforation, and the test groups (A, B and C), with 5 models each. The test groups were fixed with cannulated screws using the Asnis technique, and they had the synthesis removed, and two of the holes formed by the reinforcement technique with PMMA were filled. The biomechanical analysis was performed simulating a fall on the large trochanter using a servo-hydraulic machine.

Results All specimens of the CG and of groups A, B and C presented basal-cervical fracture of the femoral neck, except for a single model in group B, which presented a longitudinal fracture. An average of 5.4 mL of PMMA were used to reinforce the groups with filling. According to the analysis of variance (ANOVA) and the Tukey multiple comparison test, at the level of 5%, we observed that the CG presented significant differences in relation to groups A and C in the following parameters: maximum load, energy up to the fracture, and displacement.

Keywords
- hip fractures
- femoral fractures
- osteoporosis
- polymethyl-methacrylate

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Conclusion We observed that groups A and C, when compared to the CG, showed significant differences in the observation of displacement, maximum load, and energy until the fracture.

Resumo

Objetivo Avaliar, por meio de ensaio biomecânico, a carga máxima, a energia, e o deslocamento necessários para a ocorrência de fratura em modelos sintéticos de fêmures após a retirada de parafusos acanulados e a realização de técnica de reforço com polimetilmetacrilato (PMMA) em diferentes posições combinadas.

Métodos Foram utilizados 25 ossos sintéticos divididos em 4 grupos: o grupo controle (GC), com 10 modelos sem perfuração, e os grupos teste (A, B e C), com 5 modelos cada. Os grupos de teste foram fixados com parafusos acanulados pela técnica de Asnis, e tiveram a síntese removida e o preenchimento de dois dos orifícios formados por técnica de reforço com PMMA. A análise biomecânica foi realizada simulando queda sobre o grande trocânter utilizando máquina servo-hidráulica.

Resultados Todos os corpos de prova do GC e dos grupos A, B e C apresentaram fratura baso-cervical do colo femoral, exceto um modelo do grupo B, que apresentou fratura longitudinal. Foi utilizada uma média de 5,4 mL de PMMA no reforço dos grupos com preenchimento. Segundo a análise de variância (*analysis of variance*, ANOVA) e o teste de comparações múltiplas de Tukey, no nível de 5%, observou-se que o GC apresentou diferença significativa em relação aos grupos A e C nos seguintes parâmetros: carga máxima, energia até a fratura, e deslocamento.

Conclusão Observou-se que os grupos A e C, quando comparados ao GC, apresentaram diferenças significativas na observação do deslocamento, da carga máxima, e da energia até a fratura.

Palavras-chave
- fraturas do quadril
- fraturas do fêmur
- osteoporose
- polimetilmetacrilato

Introduction

The exponential increase in the elderly population in the world generates a change in the pattern of morbidity and mortality and in the way we cope with common pathologies in this age group, as is the case of osteoporosis. The low bone density, the deterioration of the microarchitecture, and the increase in frailty may result in a decrease in the mechanical resistance of this tissue, predisposing it to fractures due to low energy traumas, and the fracture of the proximal end of the femur (PEF) has the highest morbidity and mortality rates.[1–3]

The surgical treatment of these fractures aims to give the patients conditions to return to their activities. There are several recommended treatments, such as intramedullary tutors, cannulated screws (CSs) and/or the sliding tube plate (STP). There is also the possibility of joint replacement by hip arthroplasty, in order to reduce the chance of clinical complications due to immobility of the patient.[4]

Migration is common in the use of synthesis and thus the persistence of pain in the gluteal and thigh regions due to their prominence;[5] this is one of the indications for removal of the synthesis, as well as failure of the implant or infection. The removal of implants can cause greater local fragility and, with this, possible fractures of the PEF, especially in patients with low bone quality.[3,6,7]

Therefore, evaluating the maximum load, energy and displacement necessary for fracture occurrence in synthetic femur models, after the removal of the CSs and the performance of the reinforcement technique with polymethylmethacrylate (PMMA) in different combined positions, through a static bending test simulating a fall on the trochanter, can provide results that determine the development of an alternative technique in the solution of cases in which removing the synthesis is necessary.

Material and Methods

We used 25 synthetic c1010 models manufactured in Brazil (Nacional Ossos, Jaú, SP, Brasil), made in spongy and cortical polyurethane with 10 pounds per cubic foot (lb/ft^3), with 12-mm medullary channels, of the same lot and same model, which were divided into 4 groups: the control group (CG) with 10 models, and test groups A, B and C, each with 5 models.

The CG was composed of synthetic models with intact external and internal integrity. The models in groups A, B and C, without the performance of previous fractures, were fixed according to the technique for type-Asnis CS (inverted triangle): they were submitted to the introduction of a guide wire with the aid of radioscopic control, in the form of pairs equidistant from each other, up to a distance of 5 mm from the surface of the femoral head. The measurement of these wires was performed with the standard measuring tool provided by the manufacturer (Ortosintese, São Paulo, SP, Brazil), to determine the length of the 95-mm screws. The passages were performed using a cannulated drill from the same

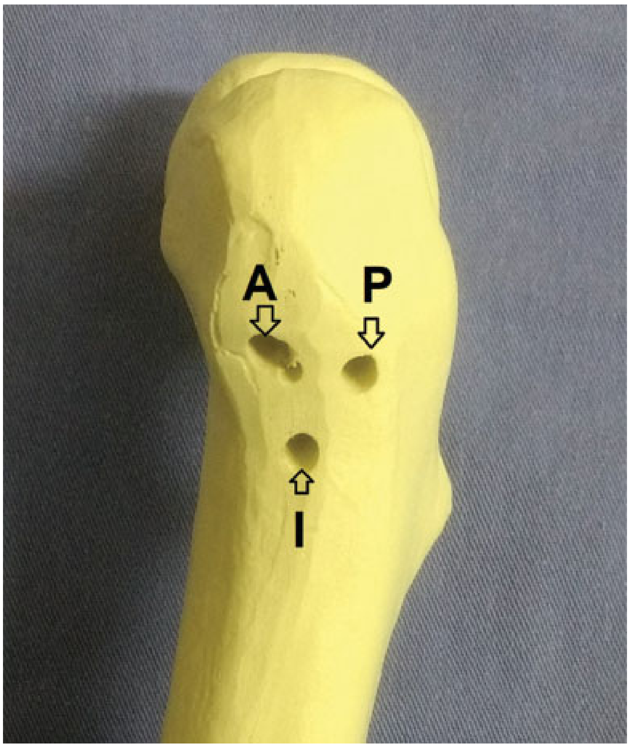

Fig. 1. Copy of the synthetic model after removal of the synthesis material, evidencing the holes formed (A: anterior hole; P: posterior hole; I: bottom hole).

manufacturer for the use of 7.5-mm CSs, which were introduced in each passage, with the length previously determined by the acquired measurement (95 mm), and then their removal was performed (►**Figure 1**).

After the removal of the implants in groups A, B and C, the synthetic models were submitted to a reinforcement technique with the use of PMMA bone cement (Biomecânica, Jaú, SP, Brazil) of normal viscosity, filling the passage of two CSs in each bone; the PMMA was introduced anterogradely, with the aid of a 20-mL syringe, and then we calculated the volume of PMMA used. In group A, the filling occurred in the holes of the anterior and lower positions; in group B, in the anterior and posterior positions; and in group C, in the posterior and lower positions (►**Figure 2**).

All samples from the 4 groups were submitted to static bending tests, using the model MTS 810 - FlexTest 40 servo-hydraulic machine (MTS Systems, Eden Prairie, MN, US) with a capacity of 100 kN. Each femur was fixed to the test device leaving 150 mm of its length outside the clamping device, towards the hydraulic piston, positioned at the base of the test machine at a 10° horizontal inclination, and at 15° of internal rotation, measured by means of a goniometer, keeping the larger trochanter supported on a silicone disc with 8 cm in diameter (►**Figure 3**). A preload of 40 N was applied, and a speed of 2 mm/s of piston displacement was used, directing the head of the femur to the fracture (►**Figure 3**). The maximum load values were measured in Newtons (N); the energy up to the fracture, in Joules (J); and the displacement, in millimeters (mm).

The results were obtained through an inferential analysis, composed of the analysis of variance for one factor (one-way ANOVA) together with the Tukey multiple comparison test, in order to verify if there was a difference in maximum load, displacement and energy until the fracture among the four groups. The criterion to determine significance was the level of 5%. The statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS, IBM Corp., Armonk, NY, US) software, version 20.0.

Results

All specimens in the CG and in groups A and C presented basal-cervical fractures of the femoral neck (►**Figure 4**). In group B, specimen B1 presented a longitudinal fracture in the subtrochanteric region (►**Figure 3B**), and all other specimens in group B also presented basal-cervical fractures of the femoral neck.

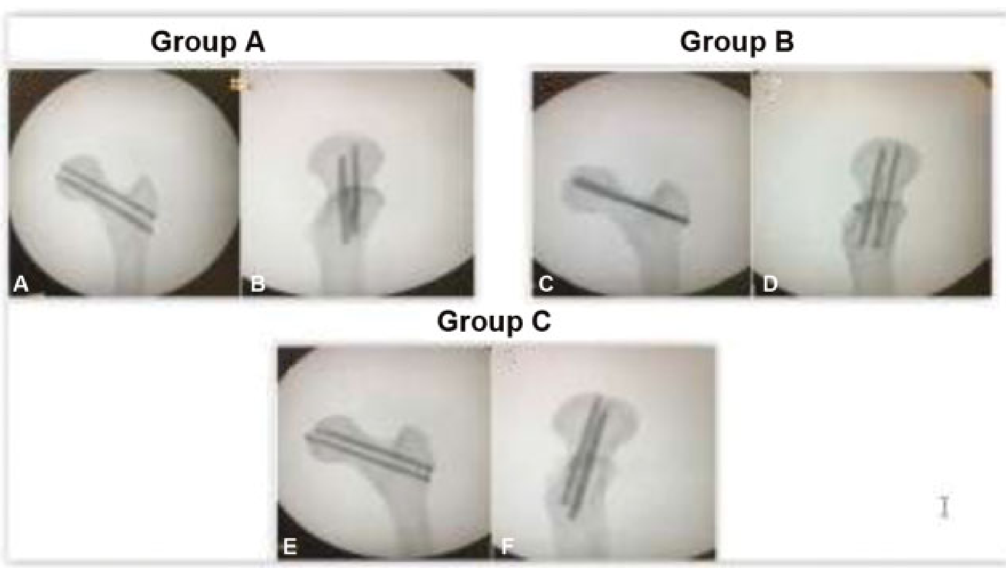

Fig. 2 Fluoroscopic images in anteroposterior and profile incidences of the models in groups A, B and C respectively, after filling their holes with PMMA. (**A/B**): reinforced anterior and lower holes; (**C/D**) reinforced anterior and posterior holes; (**E/F**): reinforced back and bottom holes).

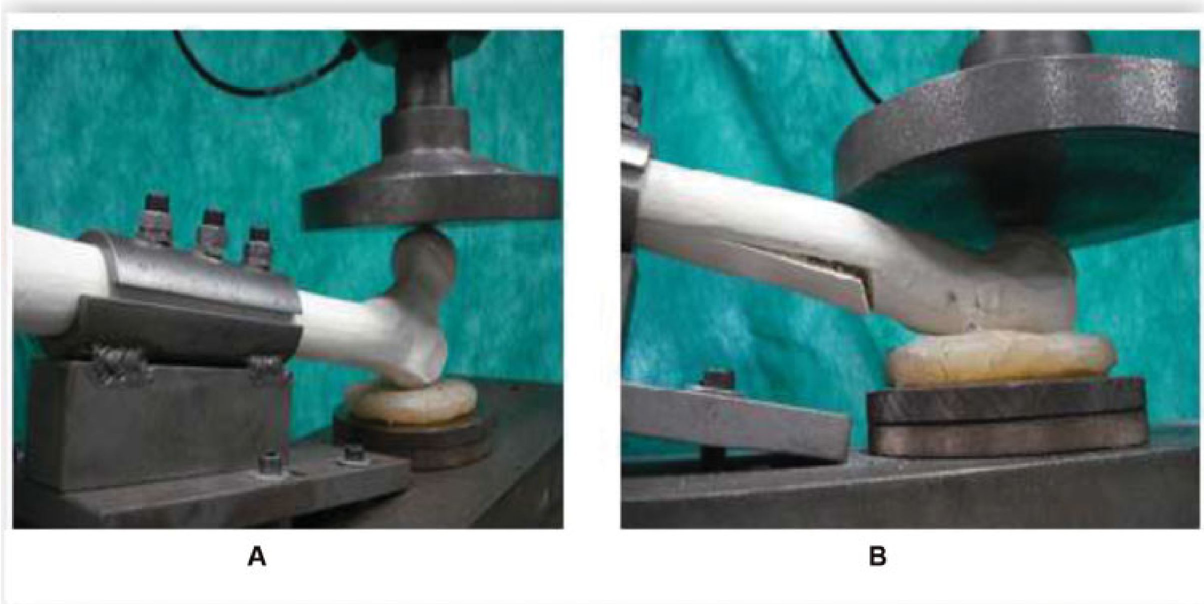

Fig. 3 Synthetic model in group B - (**A**) synthetic femur model fixed on the device during the test, demonstrating the position, and (**B**) after the test, presenting a longitudinal fracture.

Fig. 4 Synthetic femur model with basal-cervical fracture.

The amount of PMMA used to fill the two passages of the CSs in each model in groups A, B and C presented an average of 5.4 mL.

The parameters analyzed in the CG and in groups A, B and C presented the following means, and their respective standard deviations: maximum load in N ([935] ± 290; [1,320] ± 160; [1,229] ± 264; [1,310] ± 63); energy up to the fracture ([7.0] ± 2.5; [8.6] ± 2.1; [10.2] ± 3.2; [11.0] ± 2.1); and displacement in mm ([7.7] ± 1.2; [6.4] ± 0.6; [6.7] ± 1.0; [6.7] ± 0.8) (►**Table 1**).

►**Table 1**, as well as ►**Figures 5**, **6** and **7**, provide the descriptive parameters of maximum load, energy up to the fracture, and displacement respectively, according to each group, and the corresponding descriptive level (*p*-value) of the one-way ANOVA. The Tukey multiple comparison test was applied to identify which groups differed significantly from each other at the level of 5% ("significant differences" column on the table).

We observed that the CG, according to the one-way ANOVA, presented a significant difference in relation to groups A and C in the following parameters: maximum load ($p = 0.012$), energy up to the fracture ($p = 0.037$), and displacement ($p = 0.082$).

Discussion

There are several techniques described for the treatment of femoral-neck fractures, which can range from fixation using CSs to hip arthroplasty. Multiple cannulated screws (MCSs) may vary according to the amount and position of the implants, factors that directly impact on the stability of the fracture/synthesis set. It is known that the use of three screws in an inverted triangle conformation provides more stability, but the use of two screws may be enough for some types of (stable) fractures. Thus, the importance of what is described here lies in the high incidence of the use of CSs in the treatment of PEF fractures.[7]

Bone fragility in the passage of the implant after removal proved to be a risk factor for fractures of the proximal femur.[8,9] Therefore, the removal of the material is reserved for selected patients,[5] thus ratifying the importance of the descriptions of experimental studies that demonstrate the mechanical behavior of this region after the removal of the synthesis.

A work with similar methodology, but comparing synthetic models with and without filling after the removal of the CSs in the inverted triangle position, performed by Anderson et al.[10] in 2019, describes statistically significant results.[10] In the present study, we note that the tension provided by reinforcement with PMMA is relevant. The resulting fracture profile leads us to believe that the amount of passage filled as well as the site of the reinforcement are more important than the amount of PMMA used in the technique. This result corroborates the findings of the aforementioned study.[10]

Table 1 Mean of maximum load (N), displacement (mm) and energy until the fracture (J) according to each group

Variable	N	Average	95% confidence interval for average	Minimum	Maximum	*p*-value[a]	Significant differences[b]
Maximum load (N)							
Control group	10	935	755–1,115	555	1,399	0.012	Control group ≠ groups A and C
Group A	5	1320	1,180–1,460	1,120	1,566		
Group B	5	1229	998–1,460	1,063	1,691		
Group C	5	1310	1,256–1,365	1,241	1,370		
Displacement (mm)							
Control group	10	7.71	6.9–8.4	5.3	9.5	0.082	Trends in the control group ≠ group A
Group A	5	6.42	5.9–6.9	5.8	7.0		
Group B	5	6.76	5.9–7.6	5.5	7.8		
Group C	5	6.70	6.0–7.4	5.8	7.6		
Energy up to the fracture (J)							
Control	10	7.05	5.5–8.6	4.4	10.4	0.037	Control group ≠ group C
Group A	5	8.60	6.7–10.5	6.5	11.6		
Group B	5	10.2	7.4–13.0	6.0	14.3		
Group C	5	10.9	9.1–12.8	8.6	14.0		

Notes: [a]One-way analysis of variance (ANOVA). [b]Significant differences at the level of 5%, according to the Tukey multiple comparison test.

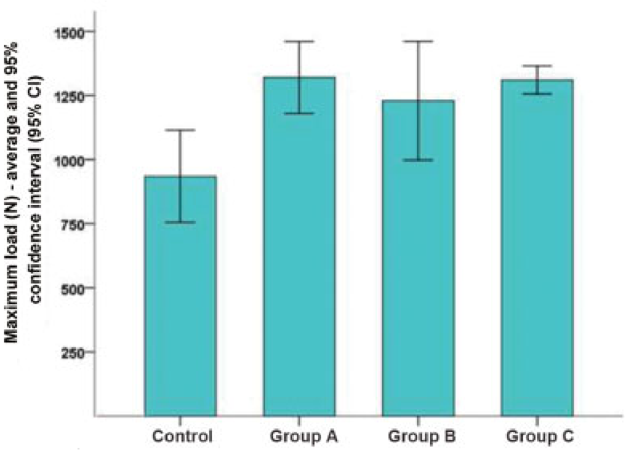

Fig. 5 Maximum Load (N) according to each group that was filled.

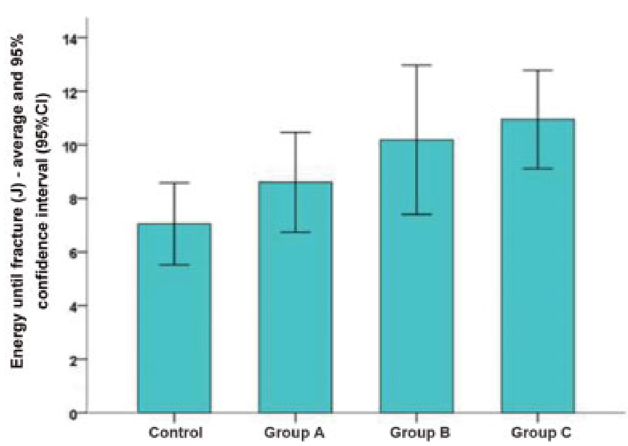

Fig. 6 Energy up to fracture (J) according to each group that was filled.

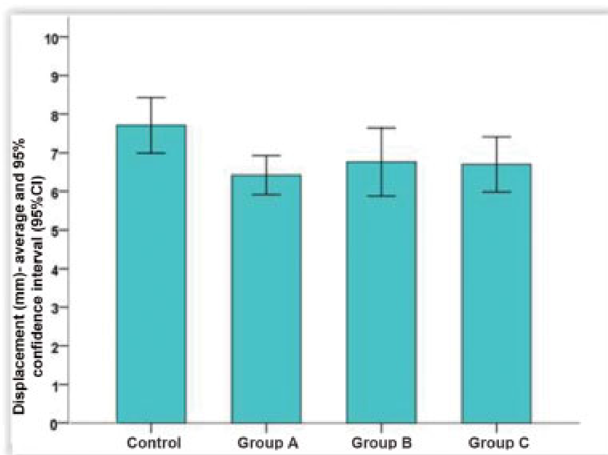

Fig. 7 Offset (mm) according to each group that was filled.

Biomechanical and structural differences between synthetic bones and cadaver bones do not enable the comparison of absolute values regarding scientific developments. Nevertheless, there is fairness in noting the benefit of bone reinforcement with the use of PMMA.[11–13] The use of PMMA bone reinforcement after implant removal already presents experimental results.[11,14,15]

It should also be considered as a possible bias in the clinical condition the fact that, with consolidation, there is a decrease in the actual length of the long axis of the femoral neck, which makes the lever arm smaller and may eventually increase the load and energy required for a new fracture.

It is possible that the observation of a fracture in a single model in group B occurred by structural alterations inherent to the manufacturing, since the fracture behaved in an atypical way, uncommon in clinical situations with skeletally mature bones. It should also be noted that the groups that presented significantly positive parameters regarding the reinforcement with PMMA had in common the filling of the lower orifice, so that this region may be a site in which there is a need to strengthen the mechanism studied in procedures related to prophylaxis of the fracture of the PEF.

There is an inherent difficulty in conducting experimental tests using cadaveric models in Brazil, making the use of synthetic models in this type of experiment almost mandatory, a fact that does not diminish their importance, as long as they are always performed with a control group.

Cadaveric human models present heterogeneity in the samples (regarding variables such as bone density and dimensions) that may compromise the observation of the parameters analyzed, when they are not submitted to a standard methodology of choice that involves densitometry, radiographs and other imaging exams, a fact not necessary in synthetic models. The choice of such models enables the standardization of the methodological evaluation and ensures that the biomechanical characteristics can be compared among the groups.

Conclusion

We observed that groups A and C, when compared to the CG, showed significant differences in the observation of displacement ($p = 0.082$), maximum load ($p = 0.012$) and energy until the fracture ($p = 0.037$).

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Conflict of Interests
The authors have no conflict of interests to declare.

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