Energy Required for Fracture in Synthetic Proximal Femoral Models After Synthesis Material Removal: a Biomechanical Study Using Cannulated Screws, Dynamic Hip Screws, and Proximal Femoral Nails*

Energia necessária para a ocorrência de fratura em modelos sintéticos de fêmur proximal após retirada de material de síntese: Um estudo biomecânico com parafuso canulado, parafuso dinâmico do quadril e haste femoral proximal

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Abstract

Objective The present study aims to identify the energy required for synthetic proximal femoral fracture after removal of three implant types: cannulated screws, dynamic hip screws (DHS), and proximal femoral nail (PFN).

Methods Twenty-five synthetic proximal femur bones were used: 10 were kept intact as the control group (CG), 5 were submitted to the placement and removal of 3 cannulated screws in an inverted triangle configuration (CSG), 5 were submitted to the placement and removal of a dynamic compression screw (DHSG), and 5 were submitted to the placement and removal of a proximal femur nail (PFNG). All samples were biomechanically analyzed simulating a fall on the greater trochanter using a servo-hydraulic machine to determine the energy (in Joules [J]) required for fracture.

Keywords
- hip
- hip fractures
- fracture fixation
- device removal

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Results All samples presented basicervical fractures. The energy required for fracture was 7.1 J, 6.6 J, 6 J, and 6.7 J for the CG, CSG, DHSG and PFNG, respectively. There was no statistically significant difference (considering a 95% confidence interval) in energy among the study groups ($p = 0.34$).

Conclusion There was no statistically significant difference in the energy required to cause a synthetic proximal femoral fracture after removing all three implant types and simulating a fall over the greater trochanter.

Resumo

Objetivo Identificar a energia necessária para ocorrência de fratura do fêmur proximal em osso sintético após a retirada de três modelos de implantes: parafusos canulados, parafuso dinâmico do quadril (*dynamic hip screw*-DHS) e haste femoral proximal (*proximal femoral nail*-PFN).

Métodos Foram utilizados 25 modelos de ossos sintéticos da extremidade proximal do fêmur: 10 unidades de grupo controle (GC), 5 unidades após colocação e retirada de 3 parafusos canulados colocados em configuração de triângulo invertido (GPC), 5 unidades após colocação e retirada do parafuso de compressão dinâmico (GDHS) e 5 unidades após colocação e retirada da haste de fêmur proximal (grupo GPFN). Uma análise biomecânica foi realizada em todas as amostras simulando uma queda sobre o grande trocânter utilizando uma máquina servo-hidráulica com o objetivo de verificar a energia (em joules [J]) necessária até a ocorrência de fratura nos diferentes grupos.

Resultados Todos os grupos apresentaram fratura basocervical. Os grupos GC, GPC, GDHS e GPFN apresentaram, respectivamente, valores de 7.1J, 6.6J, 6J e 6.7J de energia até a ocorrência de fratura. Não houve diferença estatisticamente significativa (intervalo de confiança de 95%) na energia entre os grupos de estudo ($p = 0{,}34$).

Conclusão Não houve diferença estatisticamente significativa nos valores de energia necessária para ocorrência de fratura da extremidade proximal do fêmur após a retirada de três tipos de implantes utilizando modelos sintéticos simulando queda sobre o grande trocânter.

Palavras-chave
- quadril
- fraturas do quadril
- fixação de fratura
- remoção de dispositivo

Introduction

Life expectancy has increased worldwide, mainly due to improved social determinants of health. As a result, the higher number of elderly people proportionally increased the rate of chronic non-communicable diseases, including osteoporosis, which stands out as a global public health problem. Osteoporosis mainly affects the elderly population, especially female, postmenopausal patients. It is characterized by bone mineral density reduction, leading to a lower bone mechanical strength. It has an important socioeconomic impact due to the high incidence of proximal femoral fractures resulting from falls and low-energy traumas.[1,2]

These fractures are approached in a manner as to provide patients with conditions to resume normal activities as early as possible. Therefore, most cases are surgically treated with implants, such as proximal femoral nails (PFNs), cannulated screws (CSs), dynamic hip screws (DHSs), or even joint replacement (arthroplasty).[3]

Some complications associated with the surgical treatment of proximal femoral fractures may require implant removal. Synthesis material removal is indicated mainly in cases of persistent hip, gluteus, or thigh pain, and implant failure or infection.[4–6] Implant removal may predispose to femoral neck or intertrochanteric fractures, especially in elderly patients with low bone quality.[7]

Due to the various dimensions and positions of implants in proximal femoral fractures, we need to understand the biomechanical implications resulting from their removal to raising surgeons' awareness of the safety and consequences of performing such procedure.[8,9]

As such, this study aims to identify the required energy (in Joules) to cause a fracture in a synthetic proximal femur after removing three implant types: CSs, DHSs, and PFNs.

Materials and Methods

Twenty-five synthetic femurs (c1010 model manufactured by Nacional Ossos, Jaú, SP, Brazil), composed of cortical and spongy bone, with 10 pounds per cubic foot and a 12-mm spinal canal, were used. These femurs were divided into four groups: control group (CG), cannulated screw group (CSG), dynamic hip screw group (DHSG), and proximal femoral nail group (PFNG).

The CG was formed by 10 intact femurs (►**Figure 1**). For the CSG, 5 intact synthetic femurs were submitted to the placement of 3 7.5-mm cannulated screws configured in an inverted triangle. For the DHSG and PFNG, each group

Fig. 1 Control group (CG) model.

consisted of five synthetic femurs submitted to implant fixation using the *Arbeitsgemeinschaft für Osteosynthesefragen* (AO) technique shown in ►**Figure 2**. The sliding screws had 12 mm in diameter for the DHSG and 10.5 mm for the PFNG. Eventually, all implants were removed, and the bones were sent to the biomechanical analysis laboratory.

Fig. 2 Cannulated screw (CSG), dynamic hip screw (DHSG) and proximal femoral nail (PFNG) group samples after implant placement.

Fig. 3 Experimental model on the biomechanical test platform.

Tests were performed in static flexion using a servo-hydraulic machine (MTS 810 model, FlexTest 40, MTS Sistemas do Brasil Ltda., São Paulo, SP, Brazil) with a 100 kilonewtons power. Each femur was attached to the test device leaving 150 mm of its length outside the machine, towards the hydraulic piston at its base with a horizontal inclination of 10° and 15° in internal rotation according to a digital goniometer. The greater trochanter was supported by a silicone disk with 8 × 2-cm in diameter (►**Figure 3**). A preload of 40 Newtons was applied at a speed of 2 mm/s, followed by load applied to the femoral head until fracture (►**Figure 4**); the energy was determined in Joules (J).

The results were obtained through an inferential analysis using selected parameters data and submitted to a one-way analysis of variance (ANOVA) to detect a potential significant difference among the groups. Significance was set at 5%. The statistical analysis was performed using the IBM Statistical Package for the Social Sciences (SPSS) Statistics, version 20.0 (IBM SPSS Statistics, Armonk, NY, USA).

Results

All samples presented basicervical fractures.

Fig. 4 Experimental model after fracture.

Table 1 Energy (in Joules) required for fracture in each experimental model

Variable	n	Mean value	95% CI for mean value	Minimum value	Maximum value	*p*-value*
Energy (J)						
CG	10	7.1	5.5 - 8.6	4.4	10.4	
CSG	5	6.6	4.3 - 8.9	4	10	
GDHS	5	6	4.9 - 7.1	4	7	
GPFN	5	6.7	6.1 - 7.3	6.2	7.9	0.78

Abbreviations: CG, control group; CSG, cannulated screw group; DHSG, dynamic hip screw group; PFNG, proximal femoral nail group; CI, confidence interval; J, Joules.
*One-way analysis of variance (ANOVA).

The energy required for fracture was 7.1 J, 6.6 J, 6 J and 6.7 J for the CG, CSG, DHSG, and PFNG, respectively, as shown in ►**Table 1**.

A one-way ANOVA revealed that there was no statistically significant difference in the energy required for fracture ($p = 0.78$) among the study groups.

Discussion

Proximal femoral implant removal can result in local biomechanical changes. For instance, DHS removal can generate bone defects in the subtrochanteric area due to its position, while PNF removal causes a major bone defect in the greater trochanter. Therefore, before implant removal from the proximal femur, the surgeon must consider the biomechanical changes and the potential complications resulting from the procedure.[7–9]

In this study, synthetic bones were chosen to standardize the biomechanical properties between samples and to minimize bone-inherent differences (bone density, length, biochemical composition, age, diameter).[10] The simulated fracture mechanism, which was the fall over the greater trochanter, is accepted as the most common in this type of injury, especially in the elderly population.[11]

All fractures in our study were basicervical injuries. The literature suggests that, after implant removal, a bone failure aggravated by the low bone density in elderly patients may contribute to the weakening of the femoral neck region, making it more susceptible to stress and fracture.[12–14] Other studies have suggested that pain after fracture consolidation may have been misinterpreted, consisting in a clinical sign of stress injury at the femoral neck, which would contribute to fracture after implant removal.[15]

In addition, our results show a regular trend towards lower maximum energy in the CSG, DHSG, and PFNG when compared to the CG, even though there were no statistically significant differences. Yang et al., in a similar biomechanical study using 15 cadaveric femurs, also failed to demonstrate a significant difference in the maximum energy required for proximal femoral fractures after PFN and DHS removal.[6,9]

Other studies have tested femoral reinforcement with bone cement as a technique to protect osteoporotic proximal femurs from fractures after synthesis material removal. One of these studies used synthetic femurs divided into two groups, with or without bone cement reinforcement after DHS removal, and performed biomechanical tests to determine the maximum energy required for fracture. Interestingly, no statistical difference was found in the maximum energy required for fracture, suggesting that cementation after implant removal has no benefit.[8,16]

As limitations of our study, we realized that the load applied to the models was essentially a pure lateral compression force, although other variables, including rotational and axial forces, may play a role in vivo. Another important limitation was the use of a synthetic bone model. We know that it does not reproduce the true biomechanics of human bones, especially in the elderly population, which presents low bone mineral density and is most susceptible to proximal femoral fractures. In addition, morphological changes inherent to fracture healing, such as callus formation, remodeling and malunion, were not evaluated. Synthetic models do not allow for ethnicity, age, metabolic conditions, and lifestyle habits assessment. However, the iatrogenic aggression necessary to remove the synthetic material cannot be evaluated. Last, the sample was restricted to 25 bones, which is limited, due to the high cost of the models.

Conclusion

None of the evaluated bone models presented significant differences in the energy required for fracture when compared to the control group. Further studies are needed to corroborate our results, preferably with bone models that biomechanically resemble those of the population with a higher incidence of proximal femur fracture.

Conflict of Interests

The authors declare no conflict of interests; this research was not sponsored by any public or private entities.

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