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Original Article

Effect of removal and reinsertion of force-closed stems on deformation of total hip arthroplasty[☆]

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ABSTRACT

Objectives: This study investigated removal of a force-closed stem, done in order to improve acetabular exposure during revision, with reinsertion afterwards. It is unknown how much this procedure modifies the stem/cement interface.

Methods: Three tapered stem models were implanted into composite femurs. Strain gauges were embedded in the medial aspect of the cement mantle and in several positions on the outer surface of the femurs. The deformation was measured during static loading, which was applied at two different times: after implantation and after one million loading cycles, followed by stem removal and reinsertion. The t test was performed. The differences in deformation were compared (at $p \leq 0.05$) between the two static loading times and among the three stem designs.

Results: No significant differences in deformation were found after the two loading times for the three models. No significant differences in the initial deformations of the three models were found for most of the gauges attached to the femurs.

Conclusions: Reinsertion of the force-closed stem does not alter the load transmission from the stem to the cement and to the surface of the femur, even after one million loading cycles.

Efeito da remoção e reinserção de hastes tipo *force-closed* nas deformações da artroplastia total de quadril

Palavras-chave:
Artroplastia de quadril
Desenho de prótese

RESUMO

Objetivos: Estudo da remoção de haste do tipo *force-closed* e a sua reinserção posterior para aumentar a exposição do acetábulo durante a revisão. Não é conhecido o quanto esse procedimento modifica a interface haste/cimento.

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Fenômenos mecânicos

Métodos: Três modelos de hastes afiladas foram implantadas em fêmures compósitos. Extensômetros de deformação foram embebidos no aspecto medial do manto de cimento e em diversas posições sobre a superfície externa dos fêmures. As deformações foram medidas durante cargas estáticas, as quais foram aplicadas em dois diferentes momentos: após a implantação e após um milhão de ciclos de carga, seguido pela remoção e reinserção. O teste *t* foi feito. As diferenças entre as deformações foram confrontadas com $p \leq 0{,}05$ entre os dois momentos de carga estática e entre os três projetos de hastes.

Resultados: Não foram encontradas diferenças significativas nas deformações após os dois momentos de carga para os três modelos. Não foram encontradas diferenças significativas nas deformações iniciais dos três modelos para a maioria dos extensômetros aderidos aos fêmures.

Conclusões: A reinserção de haste do tipo *force-closed* não altera a transmissão de carga da haste para o cimento e para a superfície do fêmur, mesmo após um milhão de ciclos.

Introduction

Polished, tapered, cemented and glue-free stems are widely applied in total hip arthroplasty. These stems function as a conical interference assembly, in a manner known as “force-closed”.[1] Theoretically, given that there is no strong chemical bond between the metal stem and the polymer cement, it should be possible to remove the stem from the cement and obtain the same interfacial interaction after its reinsertion.

In the case of acetabular revision, removal of the stem is of interest because this increases the degree of exposure of the acetabulum and reduces the duration of the operation. Nabors et al.[2] conducted a 10-year clinical follow-up on 24 cases of acetabular revision, in which force-closed stems were removed and reinserted. Nabors et al.[2] and Bell et al.[3] also evaluated the rotational stability of the stems through mechanical tests and did not find any evident loss of stem stability caused by the reinsertion. Nonetheless, changes at the interface between the stem and cement may occur after stem reinsertion.[4] The small interfacial spaces that may arise after the residual tensions in the cement have relaxed possibly do not produce any significant changes to the rotational stability of the stem over the short term. However, these spaces may produce changes to load transmission from the stem to the cement. Norman et al.[5] discovered that changes to the interfacial interaction between the stem and cement had a profound influence on alterations to the deformations that were transferred to the cement and to the femur. Measurements of electrical resistance through the extensometry technique (*i.e.* using strain gauges) can be used to detect such alterations to these deformations.

The present study had the objective of ascertaining whether there were any changes to deformations either in the cement or in the femur after removal and reinsertion of the stem. If the deformations of the primary arthroplasty did not differ significantly from the deformations after the reimplantation, this would be a strong indication that the interface between the stem and cement had been preserved and that removal and reinsertion was a safe procedure from a mechanical point of view.

Materials and methods

Commercially available force-closed stems made of stainless steel (ASTM F138) were supplied by the manufacturer (MDT Implantes, Rio Claro, SP, Brazil). The stems differed from each other regarding their transverse geometry and their tapering angles and planes (Fig. 1). The important geometric differences between the stems were the following: group A (Spoac®): proximal thickness of 12.25 mm, tapering of 1°15′ and circular cross-sectional geometry; group B (Maxima®): proximal thickness of 12 mm, double tapering (4°30′ and 1° on the lateral and medial faces, respectively, and 3°12′ in the lateral plane) and rectangular cross-section with rounded corners; group C (Spoac NC®): proximal thickness of 13 mm, triple tapering (3°, 3°30′ and 3°53′, respectively, in the frontal, lateral and transverse planes) and a rectangular cross-section with rounded corners. Two stems from each group were implanted in large synthetic femurs (3306 Pacific Research Labs).

Implantation

The appropriate stem size was selected by means of templates and the medullary cavity was obstructed by means of a polyethylene restrictor. Bone cement (Simplex P, Styker-Howmedica-Osteonics) was introduced into the medullary cavity in a retrograde manner, using a syringe. The implantation was performed by an experienced surgeon (LSMG).

Measurements on deformations

Extensometers measuring electrical resistance (*i.e.* strain gauges) were attached both to the femurs and to the cement, in specific positions of the test body, in order to enable measurement of large differences in deformation when alterations to the interface between the stem and cement occurred.[5]

The deformations of the external surface of each of the femurs were measured using seven axial extensometers (KYOWA KFG–2-120-C1-11) that were laid out along the axis of symmetry of the femurs. The deformations of each of the cement layers were measured by means of two axial

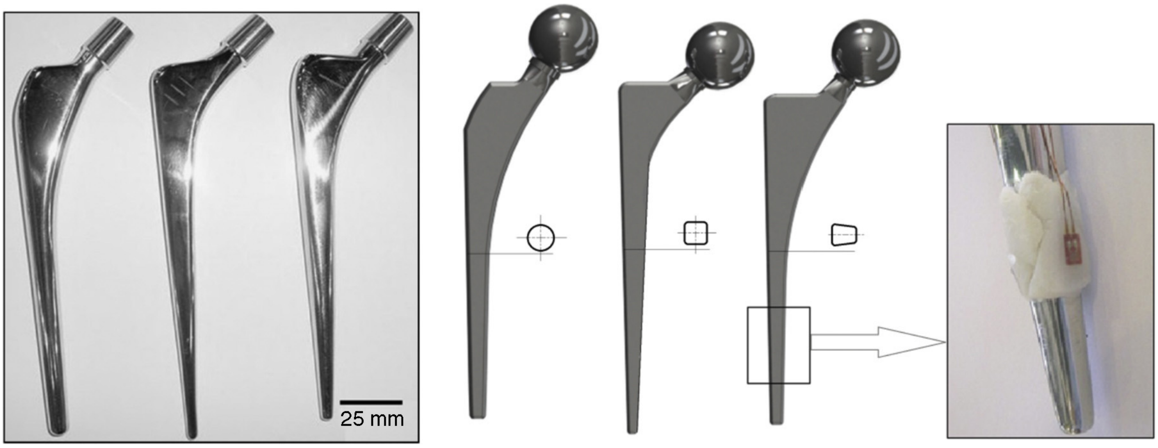

Fig. 1 – The three stem models. From left to right, conical stem (group A), doubly tapered stem (group B) and triply tapered stem (group C). The central figure shows cross-sections through the stems. The figure on the right shows an extensometer (strain gauge) attached to the cement layer close to the tip of a stem.

extensometers (Kyowa KFG02120C111-N15-C02). The extensometers were attached to the cement layers and to the femurs using similar protocols.[6] Cement layers were applied at the proximal and distal levels of each stem before its implantation, so as to enable attachment of the extensometers. The cement layers were sanded down until a thickness of 1 mm was reached. The extensometers were applied to the layers on the medial face of the stems. One of these extensometers attached to a stem at distal level before implantation is presented in Fig. 1. The extensometers were then all embedded in the cement layer during the implantation and they remained inside this layer after removal of the stems. The positions of the extensometers are presented in Fig. 2.

The deformations were measured by means of an acquisition board (HBM MGCplus). All the extensometers were calibrated by means of precision electrical resistors (Vishay Micro-measurements).

Load

The distal condyles of the femurs were fixed in a support device so as to ensure posterior inclination of 9° and lateral inclination of 10°. The condyles were embedded in PMMA resin after they had been properly fixed using screws. The test bodies were loaded into a servohydraulic test machine (MTS 810, MTS Corporation, USA). Static loads were applied to the heads of the stems after implantation and after reimplantation. Ten static load blocks were applied at a rate of 2300 N/min until reaching 2300 N, and this was followed by one minute of load-bearing and a further minute of load relief. Each deformation value was represented by the difference between maximum and minimum values produced because of the static load blocks. The mean deformation caused by the ten load blocks was used for analysis. Sine-wave cyclical loads limited between minimum peaks of 230 N and

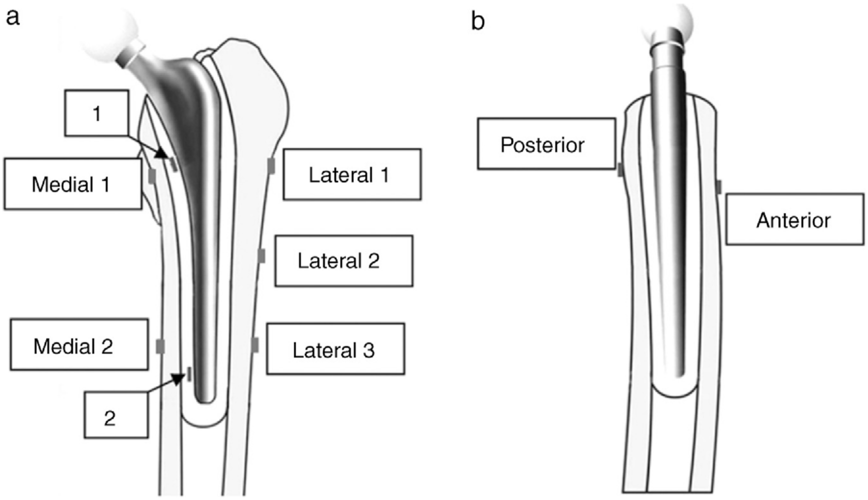

Fig. 2 – Extensometers, represented by small gray boxes. The extensometers embedded in positions 1 and 2 were laid out respectively at distances of 130 mm and 20 mm from the tip of the stem (a). The extensometers on the femurs were laid out starting from the end of the greater trochanter: (a) medial: 63 mm and 98 mm; lateral: 40 mm and 102 mm; and (b) anterior: 35 mm; posterior: 65 mm.

maximum peaks of 2300 N were applied after the initial static loads. Loading frequencies going from 7 Hz to a maximum of one million cycles were used.

Removal and reinsertion

The procedure of removal and reinsertion of the stems was conducted after application of the cyclical loads. The stems were removed by means of an appropriate extractor tool. Three hours after their removal, the stems were carefully reinserted into the cavity of the cement layer and were subjected to a final time of static loading. The removal and insertion procedure was conducted by the same surgeon who had performed the primary implantation.

The deformations were measured during static load application, both after the primary implantation and after reinsertion of the stems. The differences in deformation between the two loading times and between the initial deformations measured in the three stem models were compared by means of the *t* test, using a significance level of $p \leq 0.05$.

Results

Four embedded extensometers were damaged during the primary implantation. The damage was done to two extensometers in a test body in group B, one extensometer in group A (position 2) and one extensometer in group C (position 1). Nonetheless, it was possible to make comparisons between positions 1 and 2, respectively, in groups A and C. No significant differences in the deformations measured in the cement and in the femur were found in comparing the two loading times (Table 1). Fig. 3 shows the deformations measured by the embedded extensometers and also those measured on the medial and lateral surfaces of the femurs. The comparison between the deformations before and after reimplantation can be seen in the figure.

A comparison between the three stem models regarding the initial deformations of each position measured on the femurs was also made. Table 1 shows that in group A, the deformations tended to decrease after reinsertion of the conical stems, while in group C, the deformations in the medial and lateral directions in the triply tapered stems also decreased. On the other hand, it could be seen that in the doubly tapered stems (group B), the deformations tended to increase after reinsertion, at many of the positions measured, except in the lateral direction. However, significant differences between stems B and C were observed only in the medial 2 position and in the posterior position (Table 1 and Fig. 4). None of the other comparisons between the three stems presented any significant differences. Fig. 3 also shows that there was greater deformation close to the tops of the stems (medial 2 and lateral 3 positions, in all three stem models.

Given that only two measurement sensors showed significant differences between stems B and C, we performed linear regression analysis in which the three stem models were taken to belong to a single group. This regression also presented a strong correlation, with a coefficient of linearity of 0.91 and

Table 1 – Deformations (μm/m) measured during the initial static loading and during the static loading after reinsertion, for the nine positions measured in the three groups of stems studied. The standard deviation is presented between parentheses. Statistical differences between the initial deformations and the deformations after reinsertion, for each of the nine positions, were taken to exist when $p \leq 0.05$.

Comparisons	Medial 1	Medial 2	Lateral 1	Lateral 2	Lateral 3	Anterior	Posterior	1	2
Stem A, initial loads	−1758 (28)	−2117 (248)	339 (147)	1012 (131)	1490 (233)	−727 (73)	−905 (34)	−667 (14)	–
Stem A, loads after reimplantation	−1627 (10)	−1894 (78)	176 (114)	829 (152)	1267 (67)	−561 (56)	−789 (63)	−564 (181)	–
p value	0.13	0.31	0.54	0.53	0.48	0.32	0.10	0.56	
Stem B, initial loads	−1997 (64)	−2348 (86)	313 (68)	1144 (158)	1626 (161)	−683 (28)	−1087 (142)	–	–
Stem B, loads after reimplantation	−2012 (25)	−2476 (208)	331 (49)	1113 (133)	1607 (155)	−740 (96)	−1228 (48)	–	–
p value	0.69	0.39	0.39	0.34	0.13	0.47	0.28		
Stem C, initial loads	−2030 (48)	−1913 (103)	435 (136)	941 (157)	1424 (210)	−664 (36)	−814 (142)	–	−682 (374)
Stem C, loads after reimplantation	−1951 (418)	−1793 (158)	171 (179)	765 (61)	1368 (369)	−754 (291)	−803 (18)	–	−698 (466)
p value	0.81	0.20	0.07	0.46	0.91	0.70	0.91		0.82
p value between stems A and B	0.17	0.17	0.89	0.66	0.71	0.64	0.38		
p value between stems A and C	0.12	0.56	0.05	0.16	0.16	0.56	0.60		
p value between stems B and C	0.18	0.02	0.55	0.54	0.58	0.29	0.003		

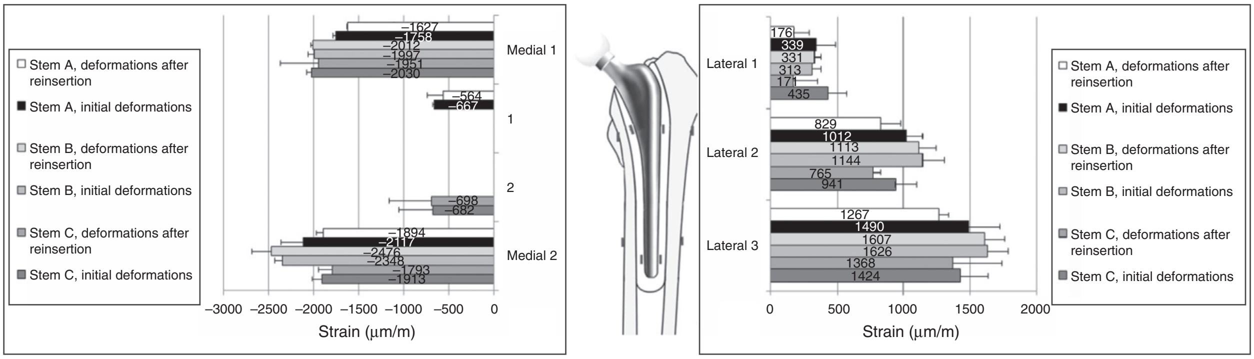

Fig. 3 – Deformations measured using the embedded extensometers and those laid out on the medial and lateral faces of the femurs.

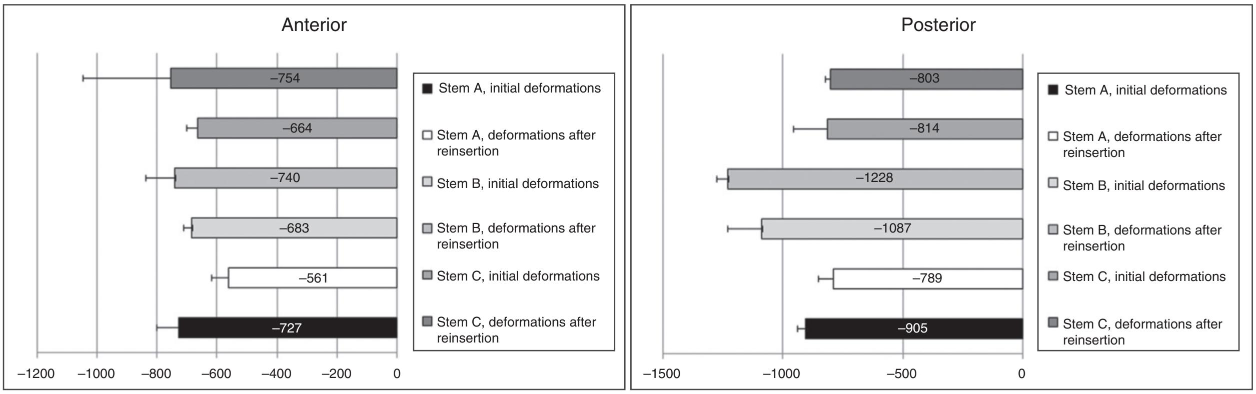

Fig. 4 – Deformations measured on the anterior and posterior faces of the femurs.

inclination from the straight line of 1.03 for the deformations measured using the embedded extensometers, and a coefficient of 0.98 and inclination of 0.96 for the deformations on the surface of the femurs (Fig. 5).

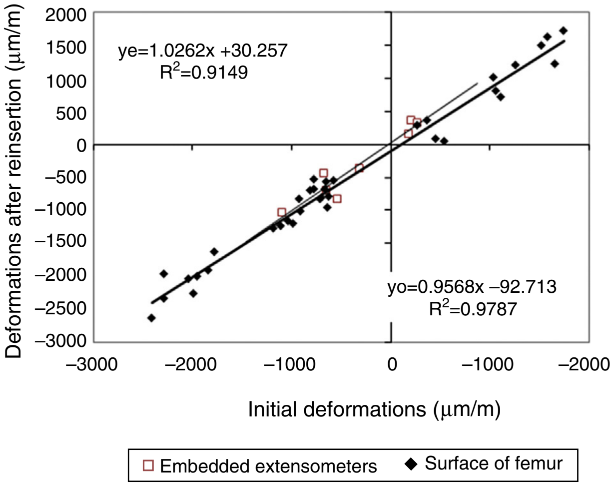

Fig. 5 – Linear regression comparing deformations caused by the initial static loads and by the static loads after reimplantation, for the three stem groups. The symbol "ye" refers to the embedded extensometers, while the symbol "yo" refers to the extensometers laid out on the external surface of the femurs.

Discussion

In the present study, the potential for alterations to the deformations transferred from the stem to the cement layer and to the femur, caused by removal and reinsertion of the stem, was investigated. Although this practice has been used in several situations in order to facilitate exposure of the acetabulum in revision surgical procedures, without any adverse clinical consequences, it still needs to be confirmed that this practice does not interfere with arthroplasty from a mechanical point of view, in order to avoid problems that might arise over the long term. Three established models of force-closed stem were tested with the aim of ascertaining whether all three models had the same mechanical behavior. These stem only presented subtle differences in design. Force-closed stems such as the Exeter stem have shown excellent long-term results.[7] In these models, the stem migrates because of the ability of the cement to flow and this enables load transmission through the cement to the femur in a more homogenous manner.[8,9] Subtle design modifications to force-closed stems have been conceived over recent decades. Examples of such alterations include those that culminated in the conception of the doubly tapered Exeter Universal stem and triply tapered C-stem.[10] Doubly tapered stems were conceived to take advantage of the cement flow characteristics. The triply tapered stem was conceived for the same reason, but with the advantage of increasing the load transferred to the calcar. Stem shape alterations such as to the cross-section, proximal geometry or tapering angles and planes may interfere with the rigidity and stability of the stem. They may also affect the load transmitted from the stem to the cement and finally to the bone tissue.

The techniques used in our study have been widely used in tests that seek to predict differences in the mechanics of arthroplasty.[6,11,12] Moreover, alterations to the interface between the stem and cement can easily be detected through using extensometers.[5] The quantity of one million load cycles was chosen in order to encourage cement flow characteristics and stem migration, in an attempt to simulate what occurs *in vivo*.

Some extensometers embedded in the cement were lost during the study. Nonetheless, it was still possible to make a comparison between positions 1 and 2 in relation to stems A and C, respectively. The comparisons between the deformations due to the initial loads and those after the reinsertion, for the embedded extensors and for those laid out on the surface of the femurs, did not show any significant differences.

The comparisons of the different positions on the femurs between the three stem models regarding the deformations due to the initial loads indicated that there were significant differences between stems B and C in the medial 2 position and on the posterior face. These differences may have been related to the subtle differences in stem design. Although these three stem models present geometrical differences, this has not be found to produce any significant differences in their clinical performances.[1,9] The design differences did not give rise to differences in the majority of the deformations that we measured. Moreover, considering that we made 21 comparisons of deformation between the three models, our finding of significant differences at only two positions is a very small proportion. For this reason, the linear regression analysis could be performed with the three models in a single group of force-closed stems. The regression analysis showed that there was a strong correlation between the deformations measured before and after the reinsertion.

Some limitations of the present study need to be highlighted. Synthetic femurs are different from natural femurs. However, various studies have shown that the mechanical properties of synthetic femurs are similar to those of natural femurs. Furthermore, synthetic femurs reduce the variation of the results, since they are manufactured from a standardized model.

The greatest limitation of the present study was that only two test bodies from each stem group were assessed. However, since no significant differences were found in comparing the deformations before and after reimplantation, in any of the extensometer positions for these two test bodies, and since the linear regression analysis presented strong correlation, we decided to conclude the experiments with only two test bodies per group. In the linear regression analysis, the three models were put together in a single group and the number of test bodies for this analysis thus increased to six. If there were any alterations at the interface between the stem and the cement, these would be seen through dispersion of the linear regression and/or distancing of the unit inclination from the straight line, and from the intercept of the line on the coordinate axis. Inclination and R^2 that are close to one (variations lower than 10%) and small intercept values (values smaller than two orders of magnitude of the deformations measured) indicated good concordance between the two times of the static tests.[6]

Another important limitation is that in clinical practice, particles and fluids may enter the cement cavity and/or the stem before stem reinsertion, and this was not investigated in the present study. Therefore, the results are applicable only in cases in which both the cavity and the stem can be protected from these particles and fluids before reinsertion.

The results from this study provide a good indication of the permanence of the interface between the stem and cement, and also the interface between the cement and femur after the reinsertion. Some studies have indicated that alterations to these interfaces promote large differences in deformations, both of the femur and of the cement.[5] Crowninshield and Tolbert[13] conducted a study on both glued and non-glued stem/cement interfaces. They used a thin layer of epoxy resin to promote reliable gluing of the stem to the cement. Alterations to the interfacial relationship were reflected in changes to the deformation measured in the cement that were as high as 100%. Studies have shown that force-closed stems migrate because of the ability of the cement to flow, although this does not represent an indication of loosening of the stem. On the contrary, cement flow may ensure good interfacial contact between the stem and the cement. This behavior promotes load transfer through the cement to the femur in a more homogenous manner, and this theoretically preserves the quality of the femur for long periods.[1,9,14–16] There are no strong chemical bonds between the metal stem and the polymer cement. Therefore, as shown in our study, it is possible to remove the stem and then obtain the same interfacial interaction after the reinsertion.

This study showed that the greatest deformations were close to the distal level (medial 2 and lateral 3 positions), for all three models. The deformations in the cement showed values greater than 1000 μm/m. These results are comparable to those of several other studies cited in this article.

Conclusions

Taking into account the experimental conditions that had been proposed for the present study, reinsertion of the same force-closed stem did not alter the transmission of deformation at the interface between the stem and cement or, consequently, to the surface of the femur. Removal and reinsertion of the stem in the cement layer did not significantly alter the mechanics of the arthroplasty, even after one million cycles.

Conflicts of interest

The authors declare no conflicts of interest.

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