

Analyzing Total Hip Arthroplasty: Straight Stem vs Anatomical Stem with Different Materials and Activities

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Introduction: Total Hip Arthroplasty involves replacing damaged parts of the hip joint with a prosthetic composed of an artificial acetabular cup and femoral head. These components, made from durable, low-friction materials, aim to restore mobility and alleviate pain in patients suffering from hip joint degeneration due to conditions such as osteoarthritis or fractures. By utilizing computational mathematical models, such as the finite element method (FEM), we can predict the behavior of materials under simulated loads from everyday activities, thereby anticipating potential failures in the femoral stem or the prosthetic material itself [1,3]. In this study, we analyze the performance of cemented and cementless hip prostheses, focusing on the influence of stem design using numerical simulation with COMSOL Multiphysics software. We examine data from a Portuguese hospital and the *OrthoLoad* database (peak stress in table 1) [3], focusing on the Exeter (cemented) and Accolade (cementless) stems, both from Stryker. The bone material considered is cancellous bone, and the implant materials are Cobalt-Chromium (Co-Cr) and Titanium (Ti-6Al-4V).

Simulation method: A highly refined computational mesh was generated to ensure high-resolution quality at contact boundaries, particularly around the implant (figures 1-A-B). For the Exeter stem, a thin layer of Polymethylmethacrylate (PMMA) was added (figure 1-C) to simulate the cement used in cemented prostheses, accurately representing its thermal properties and resistive behavior [2]. The materials used were selected from the COMSOL library, with values for Young's modulus and Poisson's ratio. The images used in the simulation were imported from GrabCAD. The Solid Mechanics interface was chosen to perform a static study due to its ability to analyze stresses and displacements.

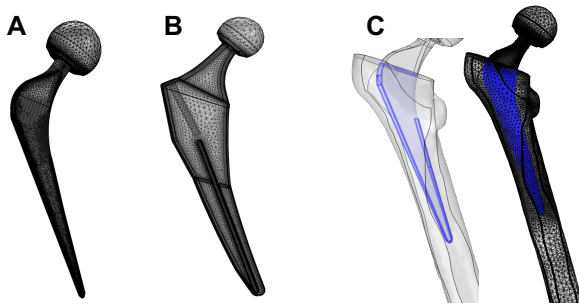


Figure 1. A. The mesh of the Exeter stem. B. The mesh of the Accolade stem. C. The location of the applied thin layer of PMMA on the Exeter stem.

Activity	Peak contact force F (N)		
	$-F_x$	$-F_y$	$-F_z$
Walking	403	249	1736
Going up stairs	446	464	1787
Going downstairs	370	292	1944
Standing up	420	105	1436
Sitting down	323	- 5	1155
Standing on 1 Leg	203	108	1785
Knee bend	290	39	1060

Table 1. Peak contact forces applied to the femoral head [3].

Results: During walking, the Accolade stem exhibits a maximum von Mises stress of 373 MPa, primarily concentrated at the neck of the stem, where as the Exeter stem shows 371 MPa with stress focused on the distal tip (figure 2-B). When considering the activity of standing on one leg, the Accolade continues to show higher stress, reaching 432 MPa at the neck of the stem (figure 2-C), while the Exeter registers 263 MPa with a peak at the neck of the stem (figure 2-D).

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The maximum displacement at the femoral head is 44.4 mm for the Accolade and 11.1 mm for the Exeter during this activity. These results highlight the differences in stress distribution and biomechanical behavior between the Accolade and Exeter stems across various physical activities, as illustrated in the figure 2 and detailed in the mentioned table 2.

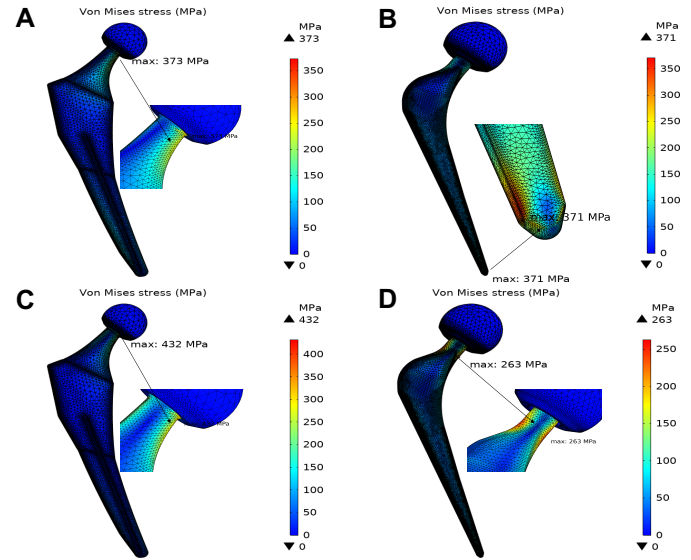


Figure 2. Results of von Mises stress: Walking activity: Accolade - A, Exeter - B. Standing on one leg activity: Accolade - C, Exeter - D.

Activity	Exeter (cemented)		Accolade (cementless)	
	Stress (MPa)	Displacement (mm)	Stress (MPa)	Displacement (mm)
Walking	371	8.98	373	41.6
Going up stairs	462	11.10	472	52.5
Going downstairs	383	9.14	459	44.4
Standing up	332	8.09	248	36.7
Sitting down	262	6.11	250	28.0
Standing on 1 Leg	263	5.77	432	27.8
Knee bend	235	5.59	220	24.1

Table 2. Results of stress and displacement for both stems across activities

Conclusions: The results highlights significant differences in stress distribution and displacement between the Exeter and Accolade stems. The Accolade stem, being cementless, primarily concentrates stress at the neck of the stem in both walking and standing on one leg activities [6]. On the other hand, the Exeter stem, being cemented, distributes stress along the length of the stem, except during the standing on one leg activity, where stress also concentrates at the neck [5]. Regarding displacement, the Accolade stem consistently shows greater displacement, indicating higher flexibility or relative movement between the stem and the bone. In contrast, the Exeter stem exhibits lower displacement values, suggesting enhanced stability [4]. These data suggest that the choice between a cemented and a cementless stem can significantly influence load distribution and relative movement at the bone-implant interface, potentially impacting the longevity and performance of the prosthesis in the patient.

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