GLOBAL 3D FINITE ELEMENT MODEL OF THE ELBOW TESTING CONTACT PRESSURES IN A RADIAL HEAD PROSTHESIS

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INTRODUCTION

Interposition of radial head prosthesis to reconstruct severe fracture dislocation of the radial head is becoming more popular in younger, active patients that require significant load transfer in the humeroradial joint. Early prostheses based on silastic were associated with poor clinical outcomes in the long term, in patients with functional requirements. This was related with low mechanical performance of silastic. Present designs of radial head prosthesis have long evolved from silastic into metals aiming a better load transfer. However, clinical data are insufficient and the discussion is open about the adequate load transfer occurring at the radial head prostheses. Finite element models have been developed to clarify load transfer, with limitations such as 2D modeling [1] or partial elbow modeling with humeroradial joint focus [2]. A finite element model of the global elbow would be required to explore the hypothesis that the load of the radial head under physiological conditions differs in a predictable way depending on the material used in the radial head.

The aim of this study is to develop a global 3D finite element model of the elbow, and to test the load transfer through a radial head of titanium versus silastic.

MATERIAL AND METHODS

A 3D FEM model of the whole elbow joint has been developed which included bone and periarticular ligaments. In addition to bone elements, a cartilage layer was introduced in the modeling of articular surfaces. The model based on tetrahedral and hexaedral quadratic elements was developed using I-DEAS software (SDRC). The joint geometry was obtained based on cadaver specimens captured by a laser 3D scanner (Roland 3D Picza,) and CT scans to define cortical and cancellous bony regions. The model was finally processed by means of Rhinoceros software (McNeel, USA).

The nonlinear analysis, including contact and nonlinear behavior for ligaments, was performed in ABAQUUS software, for a load case corresponding to a longitudinal load of 136N in the hand (60% transfer to the proximal radius), with the elbow in full extension and the forearm in neutral rotation [3], to mimic hand support and to evaluate the contact pressures between the radial head and the capitellum. This was compared to a extreme high load situation of 2250N, equivalent of 3 times the body weight for a 76.5 kg individual, as previously studied [1].

Since the aim of the study was to test the humeroradial load transfer in radial head prosthesis, proximal surface of the radial head was measured in 10 cadaver specimens to adjust the radial head surface curvature with higher precision. A mean maximum radius of 20.2 ± 0.2 measured in 10 cadaver specimens to adjust the radial head surface curvature with higher precision. A mean maximum radius of 20.2 ± 0.2 mm was obtained, in the range of previous studies [4], and the mechanical properties of a pretended radial head prostheses were incorporated into the model. Mechanical parameters of materials under testing were those of titanium (elastic modulus E=110 GPa, and Poisson’s ratio ν=0.34), silastic (E=3 MPa, as obtained from an stress-strain compression test, and ν=0.49), cortical bone (E=17 GPa, ν=0.33), cartilage (E=100 MPa, ν=0.3) and hyperelastic behavior for ligaments.

RESULTS

Figure 1 depicts a view of the obtained global 3D elbow model, including the distal humerus, the proximal radius and ulna, and the collateral and anular ligaments. Cartilage surfacing articular bone ends is also included. Figure 2 details the humeroradial joint with cartilage in the surface of capitellum, and radial head prosthesis substituting the bony radial head.

For a low load state, the contact distribution stress in the humeroradial joint with a titanium radial head give a maximum value in the center of the head, of 95 MPa for the low load state and 836 MPa for the extreme high load one. The radius of the contact area extension was 0.7 mm corresponding to a longitudinal load of 136N in the hand, while this parameter achieved 1.43 mm with the high load situation.

DISCUSSION

The proposed global elbow model allowed us to further progress in a more realistic understanding of stress distribution. The obtained results suggest that both tested materials are not fully suitable due to opposed reasons. In the titanium head stress analysis, the maximum load is high for the cartilage counterpart, even under low load conditions, while the contact area is reduced to less than 1% of the whole radial head surface. On the contrary, the silastic head produced a large contact area, up to the whole radial head surface, while the load transfer was extremely low. In consequence, different materials that metals or silastic should be investigated to obtain better load distribution stresses in the substituted radial head.

REFERENCES


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OTHER AFFILIATIONS


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