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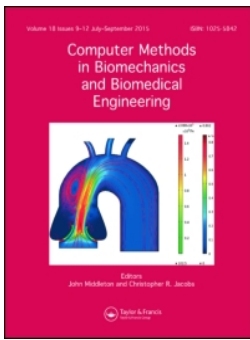
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Biomechanical analysis of the trapeziometacarpal arthroplasty failures

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KEYWORDS Trapeziometacarpal joint; prosthesis; failures

1. Introduction

Arthrosis of the trapeziometacarpal (TMC) joint, called rhizarthrosis, is a painful and disabling pathology which limits the range of motion and the strength of the thumb. When conservative treatments fail, surgical options can be considered. A recent surgical option is total prosthesis, which preserves strength and respects TMC joint kinematics. With the usual ball-and-socket design, patients obtain faster and better pain relief, stronger grip function and shorter convalescence than with trapeziectomy (Semere et al. 2015). However there are also many reports of poor results (Hansen et al. 2013). The prostheses currently used have led to various early complications, especially in active young patients. The short lifespan of these devices suggests the difficulty of designing a prosthesis which respects the complex anatomy and motions of the TMC joint. Early implant failure may reflect the fact that current devices do not exactly replicate the real kinematics. Improved knowledge of TMC kinematics with implant could also enhance the design and consequently the lifespan of implants. CT scan images were performed on different subject with different stage of arthrosis in order to understand how the prosthesis may affect the articular kinematics.

The aim of this study was to shed light on the causes of failure of TMC prostheses. The mechanical explanations for TMC prosthesis failure deserve elucidation and, while existing studies report the physiological consequences of failure, none has focused on its origin so far.

2. Methods

First, we performed CT scan acquisitions, with a Scanner General Electric light speed VCT64, of the TMC joint

under various postures of the thumb and second, we developed 3D geometrical models. Eight hands of six embalmed Caucasian cadaveric subjects, two males (3 hands) and four females (5 hands) with different degrees of rhizarthrosis according to the Dell classification (Dell et al. 1978) were used. We divided the subjects into three groups: group 1, subjects with either none or stage 1 arthrosis (2 hands); group 2, subjects with stage 2 and 3 arthrosis (4 hands); and group 3, subjects with stage 4 arthrosis (2 hands).

Three postures were chosen to cover the full range of thumb motion: commissural closing (Figure 1(A)), grip (Figure 1(B)) and opposition (Figure 1(C)). Using Mimics® (Materialise 3D, Belgium), the Dicom data CT scan acquisitions were used to develop 3D reconstructions of the TMC joint.

For each posture, based on these 3D models, we determined the position of the M1 relative to the trapezium. For each hand, considering the trapezium bone as fixed, the different postures were superposed using a surface-based registration procedure based on the iterative closest point (ICP) (Besl and McKay 1992). The method of superposition was previously described by Cerveri et al. (2010).

A CAD model of a currently-used prosthesis was coupled with the 3D reconstructions of the joint to provide numerical models of the ATM joint with a ball-and-socket implant.

Thus for each posture a numerical model of the ATM joint with a ball-and-socket prosthesis was created. Then the same superposition procedure that the one presented above was used to obtain the position of the M1/stem/neck complex relative to the trapezium/cup complex.

The potential translation of the head related to the cup was determined by the distance between the center of the

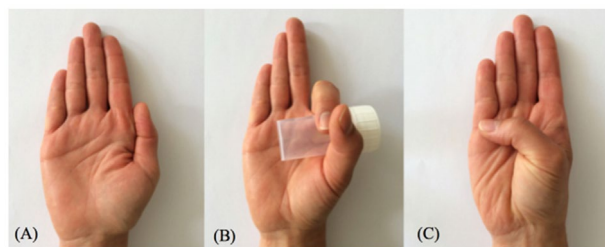


Figure 1. (A) Thumb in commissural closing posture. (B) Thumb in grip posture. (C) Thumb in opposition posture.

cup and the center of the head. This distance was calculated for each posture. If the distance is not zero there is a translation and the head of the neck penetrates the cup. In this case, the intersection volume between the cup and the head was calculated in order to evaluate the percentage of the cup volume occupied by the head.

3. Results and discussion

For the three groups, the smallest distance between the cup and the head of the prosthesis in grip posture or in opposition posture is 0.6 mm and 1.2 mm, respectively. For each posture, distances are superior to zero. Thus for each of the three groups, the head of the prosthesis translates during movements (Figure 2) and penetrates the cup.

The intersection volume between cup and head varied from 0 to 25.5 mm³. When the volume is 0, the elements do not intersect. In this case, the head is completely out of the cup. When the volume is 25.5 mm³ the elements intersect. The intersecting volume represents 76.1% of the cup volume. Thus, even with the smallest distances found in different postures, the head of the prosthesis tends to penetrate into the cup in all three groups.

4. Conclusions

In our study, the CAD model of a ball-and-socket design prosthesis implanted in each different posture of each subject shows that the original kinematics of the joint is disturbed by the prosthetic elements. The displacements of the head of the prosthesis between each posture are greater than those of the cup. Thus, the movement of the prosthesis does not fully respect the anatomical kinematics.

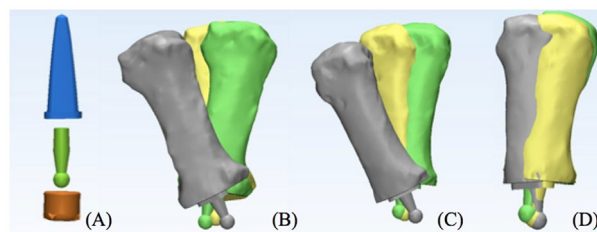


Figure 2. (A) CAD model of a currently-used prosthesis. The cup in orange, the neck in green and the stem in blue. Translation of the neck of the prosthesis for the group 1 (B), the group 2 (C) and the group 3 (D). In grey: thumb in commissure closing posture; in green: thumb in grip posture; in yellow: thumb in opposition posture.

The TMC joint is known to have non-intersecting and non-orthogonal rotation axes (Crisco et al. 2015). Moreover, this joint allowed translations of the M1 over the trapezium (Crisco et al. 2015). Then simplifying the TMC joint to a ball-and-socket articulation could lead in vivo to an over-stress of the prosthesis. The overstressing produced by this design could partly explain the short lifespan of current prostheses. In the light of this study's findings, a review of the design of these prostheses appears warranted.

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