In vivo contact stress evaluation in the trapeziometacarpal joint using finite deformation biphasic theory and mathematical modeling

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Abstract

Introduction & Objectives Osteoarthritis (OA) is a degenerative joint disease characterized by the loss of articular cartilage and remains a complex, disabling disease which cause is not completely understood.
Evaluating the stress distribution within the trapeziometacarpal (TMC) joint during daily activities is a clinically relevant way to investigate the biomechanical behavior of this complex articular system. Such insights will also lead to a better understanding of joint functioning and can help predict which part of the joint will be primarily affected by degenerative changes in the onset of OA. This is particularly important in establishing new prevention approaches.
The main objectives of this study are: (1) to evaluate the amount of stress occurring around the first metacarpal (MC1) and the trapezium bone during different isometric tasks, and (2) to identify which specific articular region undergoes the highest level of stress according to various loaded positions.
Methods After permission by the medical ethical commission of the University, CT scans were obtained from 20 female volunteers (mean age: 60.8 years) using a 64 slice Discovery HD 750 CT scanner (GE Healthcare) in AZ Groeninge, Belgium. Static CT scans (slice thickness: 0.625mm, pixel size: 0.391 mm) of the hand region were taken in three different configurations: relaxed neutral, lateral key pinch and power grasp, using a radiolucent jig with embedded load cell (Brown University, USA). The applied force was recorded during a submaximal effort (80% of maximal strength) during each task. Each scan was segmented and 3D bone models were created using Mimics v. Research 17.0 x 64 (Materialise, Belgium). Four subjects showing signs of OA were excluded from the study. The total articular area of each bone was evaluated manually using 3-matic v. Research 9.0 x 64 (Materialise, Belgium). A custom-written MatLab code - based on the finite deformation biphasic theory[1] and cartilage deformation properties taken from the literature[1], [2] - was used to evaluate the contact area for each bone, as well as the contact stress distribution. The location of the most stressed area was evaluated using a quadrant division as defined by Momose et al (1999)[3].
Results We observed no significant difference between the total articular area of MC1 and the trapezium of each subject. The trapezium, however, had a slightly smaller contact area compared to MC1. This difference was only statistically significant in the lateral pinch position ($p<0.05$; neutral: $p=0.05$; grasp: $p=0.07$). The contact stress calculation revealed a similar maximal contact stress value between the neutral position and the lateral key pinch task, while this parameter was increased during the power grasp. Similar results were found by studying the average stress distribution across the joint. We observed a stress concentration around the volar beak of MC1 and the volar-ulnar aspect of the trapezium in the neutral position, as well as in the lateral key pinch position, with a few subjects showing a stress concentration around the radial aspect of the trapezium.

The ulnar aspect of both MC1 and the trapezium was shown as the most constrained during power grasp with a strong consistency between subjects.

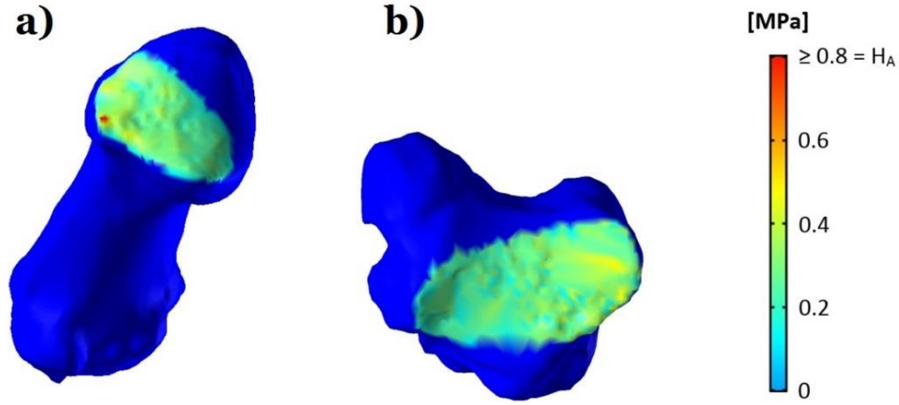

Figure: *Stress distribution in the TMC joint of one subject during power grasp - a) MC1 - b) Trapezium (right hand)*

Conclusion These results suggest that for a similar load, the contact area of the trapezium appears to be smaller than for the first metacarpal, at least in the pinch position. This could show a larger stress concentration on specific aspects of the trapezium, which we assume to indicate that the trapezium is the first bone of the TMC joint to be affected by degenerative changes. However, a larger sample size is needed to further investigate this with a higher statistical power. Such insights could be of high interest in predicting which component of the TMC joint will be primarily affected by degenerative changes. Moreover, we observed a higher average stress value in the power grasp configuration compared to the neutral position and the lateral pinch task. This could highlight two interesting findings: (1) lateral key pinch does not represent a critical task to evaluate stressful configurations in the TMC joint, (2) performing a power grasp can elicit higher amounts of stress in the TMC joint, which is of interest when studying joint stability. Furthermore, the consistency of the results regarding the stress location for the different positions provides a relevant way of understanding the biomechanics of this complex joint. This study shows the importance of performing in vivo assessments of the mechanical behavior of the TMC joint by using advanced modelling techniques to provide a better understanding of this articular system in the early onset of osteoarthritis.

References

[1] Kwan et al., J. Biomech, 23: 145-155, 1990

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[3] Momose et al., J. Hand Surg, 24A: 491-495, 1999