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

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Objective
To develop a 3D mathematical model to evaluate the contact biomechanics of the trapeziometacarpal (TMC) joint (Figure 1) during daily activities.

Clinical perspectives
→ To improve our understanding of the onset of osteoarthritis (OA)
→ To improve prevention and treatment strategies for TMC OA

Methodology
CT scans of the hand region (slice thickness: 0.625mm, pixel size: 0.391 mm) of 16 healthy female volunteers (mean age: 60.8 years) were taken in three different configurations as shown in Figure 2:

Scans were segmented using Mimics (Materialise, Belgium) and 3D models of the first metacarpal (MC1) and the trapezium were created. The total articular area was measured manually in the reference scan. A mathematical model - based on the finite deformation biphasic theory¹ and cartilage deformation properties¹,² - was developed to evaluate the projected contact area and stress distribution.

\[ \sigma = \frac{1}{2} \frac{d_1}{H_A} \left( 1 + \lambda \right) \left( \frac{1}{\lambda^2} - \frac{1}{\lambda^4} \right) \]

With:
- \( \sigma \) - Contact stress (MPa)
- \( H_A \) - Aggregate Modulus of cartilage (MPa)
- \( d_1 \) - Cartilage parameter
- \( \lambda \) - Cartilage strain (mm)

Contact patterns were observed based on color maps (Figure 3) representing the stress distribution.

Results
The total articular area of the MC1 and the trapezium presented no significant difference (p > 0.1), while a smaller projected contact area was calculated for the trapezium compared to the MC1.

Similar amounts of stress were reported in the neutral and lateral pinch configurations (average: \( \sigma_{max} = 0.46 \pm 0.15 \) and \( 0.47 \pm 0.12 \) MPa respectively), while the power grasp configuration displayed the highest stress levels (average: \( \sigma_{max} = 0.68 \pm 0.15 \) MPa).

Very consistent contact patterns were observed in the neutral (volar side) and power grasp (radial side) configurations (Figure 4). More variation was reported during lateral pinch (Figure 4).

Discussion
Potential stress concentration on the trapezium due to a smaller projected contact area.

Unexpected similarities in contact stress between neutral and lateral pinch requires further investigation through musculoskeletal modeling.

Power grasp task elicits higher contact stresses and might represent a critical configuration for clinical evaluation of the TMC joint, while lateral key pinch might create a higher joint instability and is less reproducible.

Acknowledgements
Medical Imaging Unit, AZ Groeninge (dr. Eddy Brugman)
Funding: Materialise-Kulak Chair on Hand Surgery