The effect of malalignment on knee joint contact stresses and forces

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Background

Osteoarthritis (OA) is a debilitating disease of the joints that leads to **loss of mobility and quality of life**. OA accounts for **1% of total deaths worldwide** and **costs 1% of UK's and 0.33% of the US gross national product** [1; 2].

Lower extremity malalignment (Figure 1a) and corresponding overloading and stresses in specific regions within the joint have been associated with knee OA [3]. High tibial osteotomy (HTO), using the Taylor Spatial Frame (Figure 1b), is a realignment surgery aiming at **restoring high-level function**. However, **the link between malalignment and stress in the knee is not well understood** and surgical realignment outcomes by HTO have been unpredictable [4].

The **aim** of this study is to investigate the effects of different surgical realignment techniques on the knee joint contact stresses.

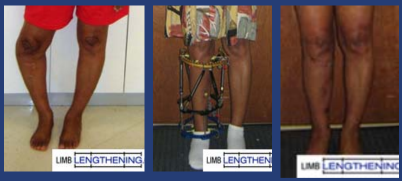


Fig.1a) lower limb varus deformation b) during treatment - up to three months, using a Taylor Spatial Frame, based on the Ilizarov method c) after treatment
With compliments from Dr. Robert Rozbruch, Hospital for Special Surgery

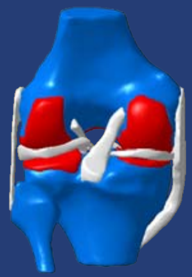


Fig. 2: Three-dimensional finite element model of the well-aligned knee joint

Methods

Geometry

- 3D geometry (Figure 2) created from MRI datasets
- SPGR :TE: 3ms, TR: 14.6ms, acquisition-matrix: 512x512, number of excitations: 2, field-of view: 15cm, slice thickness: 0.6mm, receiver BW: □} 41.7 kHz
- CUBE: TE:33ms, TR: 2500ms, acquisition-matrix: 512x512, number of excitations: 0.5, field-of-view: 15cm, slice thickness: 0.6 mm, receiver BW: □} 41.7 kHz. The in-plane resolution for both series was 0.29mm x 0.29mm.
- 3D live wire segmentation technique in Mimics ()
- 3D geometry exported to Abaqus 6.11 (Dassault Systèmes, France)
- Model verification [5].

Loading Conditions

- 300-N axial load applied to the distal tibia
- 1N pretension applied to all ligaments
- Varus malalignments applied to distal tibia for 0°, 5°, 10° and 15°
- Calculation of corresponding stresses and loads

Boundary Conditions

- Femur fixed in all six degrees of freedom
- Tibia fixed in sagittal plane
- Attachment of each ligament and cartilage to bone was modelled by merging the nodes
- Cartilage-cartilage and cartilage-meniscus contact simulated by creating contact elements between the surfaces

Material Properties

- ligaments set as homogenous, isotropic with hyperelastic behaviour
- remaining parts set as homogenous, isotropic with linear elastic behaviour

Results

•The area of tibial cartilage exposed to a pressure greater than 1 MPa in the malaligned knee increased by 36.4% (Figure 4).

•The peak pressure in the medial tibial cartilage of the intact knee was 1.6 MPa, which increased to 2.0MPa with a varus malalignment of 15° (Figure 5).

•A 10° varus malalignment results in an increase in load from 57.7% to 80.2%; a 15° varus malalignment even increases the force to 91.2% in the medial compartment (Figure 6).

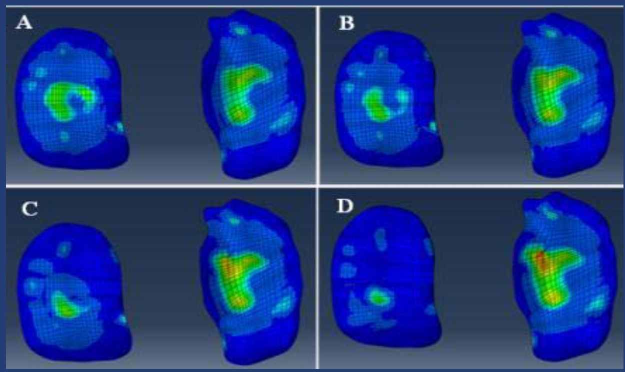
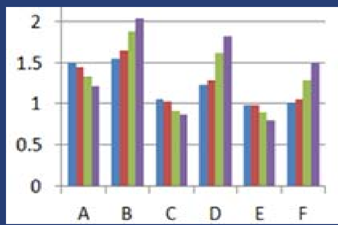


Figure4: Peak pressure distributions on tibial cartilage with an axial load of 300N and with a varus malalignment of A) 0°, B) 5°, C) 10°, and D)15°.



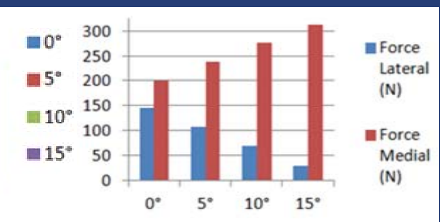


Fig. 5: A: Lateral pressure; B: Medial Pressure; C: Shear Lateral Tibial Cartilage; D: Shear Medial Tibial Cartilage; E: Shear Lateral Femoral Cartilage; F: Shear Medial Femoral Cartilage all in MPa. Fig. 6: Force in tibio-femoral compartments

Conclusion & Discussion

Knee malalignment is associated with higher stress levels. This highlights the importance of understanding HTO surgical techniques in order to improve knee joint contact mechanics and reduce peak stresses, thereby lowering the risk of OA. The results of this study are close to those of Tetsworth and Paley who reported that as little as 5° of varus ("bow-legged") mal-alignment results in an increase in compressive loading of the medial tibio-femoral compartment from 70% to 90% [6]. These results are based on one sound cadaver.

References
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