PERFORMANCE ANALYSIS OF HEXAHEDRAL MESH-MORPHING FOR THE MENISCUS OF THE KNEE

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Introduction

Generating high-quality hexahedral meshes of highly irregular tissues for finite element (FE) simulations is a laborious and time-consuming endeavour. The meniscus is an important component of the knee and challenging structure to simulate due to multi-body contact, large deformations and nearly incompressible material properties. Simulations of this nature are more accurate and likely to converge with hexahedral meshes.

Mesh-morphing has been chosen to automatically create accurate, high-quality hexahedral meshes of meniscus geometries from a single template mesh. This work aims to assess the performance of an in-house mesh-morphing strategy against a state-of-the-art hex-mesh procedure – the multi-block method (IA-FEMesh).

Methods

A set of 20 geometries (10 lateral and 10 medial) were selected which represent a variety of challenging meniscus features. Using their surface representation, 2x20 volumetric meshes were produced with either a multi-block method or our morphing strategy, using one high-quality but generic template. FE simulations with FEBio were performed as a single-condyle of the tibio-femoral joint subject to a standing compression of 500 N, incorporating idealised tibial and femoral cartilage meshes. Cartilage and meniscus were modelled as hyperelastic materials. The time taken to derive each mesh, surface error, mesh-quality and differences in simulated contact pressure and area were compared.

Results

The mesh-morphing strategy operates faster for all geometries with generation times between 83-184 s, compared to 279-8040 s for the multi-block. Overall, the multi-block method produces mesh with a lower surface error averaging 0.22 mm compared to 0.43 mm. The multi-block meshes had a lower surface error for 17/20 geometries. Mesh-morphing produces fewer very low-quality elements with an average of 0.85%, compared to 1.19% for the multi-block.

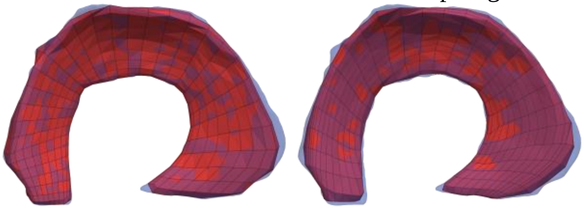

Figure 1: Surface error of the multi-block method and mesh-morphing strategy

However, the multi-block method produces fewer low-quality elements on average with 9.1% compared to 11.7%. The contact pressure distributions between the two simulations generally show strong similarities but can have different max. contact pressure locations.

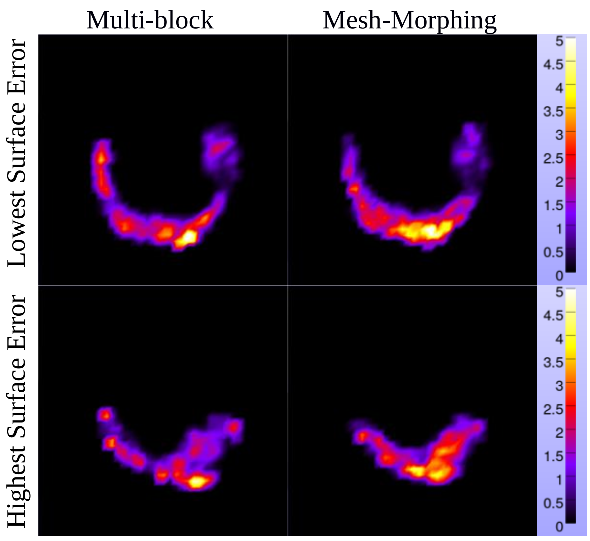

Figure 2: Contact pressure distributions (MPa) for the multi-block method and mesh-morphing strategy, for two geometries with very different surface errors

Discussion

One template was used to generate a total of 20 valid hexahedral meshes of the meniscus with reasonably low surface errors. Some differences in the contact pressure occur, mostly from mesh artefacts from the multi-block method. Other differences occur from subtle local and global surface errors. The morphed meshes distribute contact pressures more evenly due to having a smoother geometry. Although, morphed meshes that have larger surface errors tend to produce higher contact pressures.

Larger surface errors are caused from a shrinking effect from the morphing strategy and can lead to a smaller mesh than the target geometry. This will require optimizing the default mesh-morphing parameters.

The mesh-morphing strategy offers a faster, competitive and automated alternative to the semi-automatic multi-block method, with no significant difference in FE simulation outcomes.

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