Constructing smooth finite element models of patient specific ankle foot orthoses

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Introduction

In clinical practice, ankle foot orthoses or AFOs are frequently prescribed to help patients to cope with walking difficulties caused by neuromuscular problems in the lower leg region. Even though the mechanics of the AFO play an important role in the gait kinematics, the effect of different design parameters on the final mechanical response of the orthotic is not fully understood and little research on the topic has been published[1-4].

As such, it would be preferable to have a better understanding of the influence that different design parameters have on the mechanical response of AFOs. Such a knowledge would be beneficial to the design and construction of patient specific AFOs, as the labour intensive production yields orthotics that are largely dependent on both the skill and experience of the technician. This study therefore focuses on the development of a fast and user friendly methodology for constructing finite element models of patient specific polypropylene AFOs that can incorporate different design adaptations, using the open-source pyFormex[5] platform.

Materials and methods

The geometry of different patient specific AFOs was digitized with a high resolution 3D laser scanner (Rodin4D system). Scanning the thin edge of the orthosis proved to be difficult and resulted in a rather rough model edge.

The rough edges were smoothed by applying a Laplacian smoothing algorithm on the edge points, as to avoid unrealistic stress distributions near the edge of the model. For every smoothing iteration, a compensating step was provided to account for loss of surface area inherent to the smoothing of a line that has more convex than concave parts. The same approach was used for the surface smoothing, which also consisted of a smoothing step (Laplacian smoothing) and a shrinkage compensating step. In this way, the models were smoothed while taking care that accuracy of pre-processing stayed well beyond the accuracy of the scanner (0.5 mm).

Besides other mesh improving operations, special care was given to an automated positioning of the models. By positioning all models in exactly the same way, it becomes easier to compare FE simulations on different scans and to fit the same forces and boundary conditions on different models.

Results and discussion

An example of the effect of the developed procedure on an AFO model is given in figure 1. The black spots are the markings of the wholes where the straps of the AFO were attached. These are stored throughout the pre-processing so that they can be used to apply the loading conditions during the FE simulations.

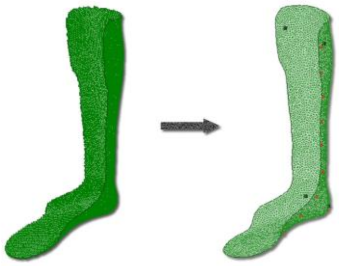

Fig. 1: Result of the pre-processing of an AFO

The surface smoothing improves the quality of the mesh significantly: in the example of figure 1, the average normalized aspect ratio (longest triangle edge length over the inradius of the triangle) improves from 1.247 to 1.158. In contrast, the edge smoothing will cause a small decrease in mesh quality, in this example from 1.158 to 1.163. This is caused by the distortion that the mesh triangles near the edge experience. After all, it is more difficult to fill a smooth edge with polygons than it is to fill a rough edge. In total, the average mesh quality defined by the aspect ratio improves by at least 30% during the whole procedure.

Conclusion

Pre-processing a model from a 3D laser scan can be a tedious job. Therefore, in this study the pre-processing of AFO models was largely automated using pyFormex. Not only does this approach save time, it also yields models that are positioned in a standardized configuration, thus making it easier to apply the same forces and boundary conditions on different models.

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