The Glasgow-Maastricht foot model

VALORISATION

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This thesis describes the development, repeatability and sources of error of the Glasgow-Maastricht foot model (GM-model). This model is the first kinematic foot model that simulates the motion of all 26 bones in the human foot. The simulation of all joints in the foot can be used to evaluate clinical treatment methods in the foot and ankle. Furthermore the GM-model has already been implemented in an inverse musculoskeletal foot model in the AnyBody Technology package. Finally by using this inverse dynamic model as an input for a forward dynamic foot model, the latter model can be used to predict the effect a foot orthosis, as was the goal of the European FP7 project A-Footprint. The A-footprint consortium existed of six SME partners (Baltic Orthoservice UAB – Lithuania, Peacocks Medical Group Ltd – UK, Firefly Orthoses Limited – Ireland, RSscan INTERNATIONAL – Belgium, AnyBody Technology A/S – Denmark, Junquera y Diz S.L – Spain) , five academic partners (Glasgow Caledonian University – UK, University of Newcastle upon Tyne – UK, Thomas More Kempen VZW – Belgium, Academisch Ziekenhuis Maastricht – the Netherlands, Stichting Fontys – the Netherlands) and one industrial partner (Materialise NV – Belgium).

The GM model to evaluate clinical treatment methods in the foot and ankle

The use of solely the kinematic model might improve the knowledge of foot and ankle biomechanics. Prior to the introduction of the GM-model (Chapter 3), the kinematic model with the highest detail of the foot had eight segments in the foot [1]. The simulation of motion between all joints enables a deeper understanding of how the various structures of the foot contribute to foot function. In the future this might lead to insight in general motion patterns of the foot and pathology specific alterations of these patters. Better understanding of these patterns is of interest for brace developers and shoe manufacturers. For example ankle braces are designed to guide ankle motion, however these restriction in ankle motion might result in compensation of this motion in the mid foot as has been shown for taping of the ankle [2].

This model creates the opportunity to study the motion in all joints in the foot (Chapter 5). For example, patients suffering on osteoarthritis on MTP 1 receive an arthrodesis on this joint. However, no consensus in literature can be found in which angle the joint should be fixed [3-5]. In addition recently first study showed compensation in hindfoot and forefoot kinematics for patients with a MTP 1 arthrodesis [6]. However, it is not yet clear what the effect of this fixation angle is on the compensation in other joints in the foot. Compensation of motion in other joints might lead to overload of these joints and therefore other complaints as is the case for patients with an ankle arthrodesis [7].

Prevention of these complaints by choosing the fixation angle with the lowest compensation in other joints is of great value for patients and society.

The GM-model in the musculoskeletal model of the foot and ankle in AnyBody

In the AnyBody Modelling System (AMS) the GM-model has been combined with an inverse dynamic model into a musculoskeletal model (see figure 7.1). The AMS is used by various companies in the sports (e.g. calculating optimal saddle height for bicycles), automotive (e.g. ergonomic design of the car interior) and orthopaedic sector (e.g. giving input for implant design). The embedding of GM-model in AMS has increased the modelled number of segments in the foot up to 26. This increase in number of segments leads to the possibility to calculate the forces in the intrinsic foot muscles needed to perform a dynamic action.

By the implementation of the GM-model in AMS it is easy accessible for a large group of researchers and clinicians. It is thereby not necessary for each separate user of the model to translate the GM-model into their own algorithms. Furthermore, by increasing the accessibility of the model next steps required before clinical use of the model can be accelerated. For example further validation of the model can be simultaneously performed by multiple research groups.

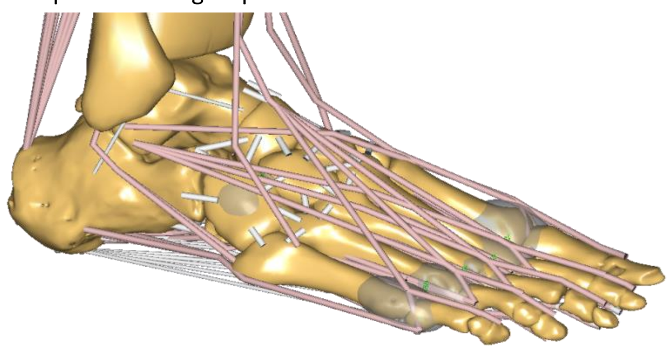

Figure 7.1 The GM-model as kinematic input of the musculoskeletal model of the foot and ankle in the AnyBody Modelling system

The musculoskeletal model recently has been used in scientific research. Al-Munajjed et al. [8] used the musculoskeletal model to investigate the metatarsal loading during gait. They showed a loading on the tarsometatarsal joints of 0.75-1.5 times body weight during the early part of stance, indicating some pre-tension from the ligaments and muscles. This is of clinical interest since dorsal displacement of the metatarsal head is a common complication after MT 1 osteotomies [9]. Before the introduction of this model, these forces could not be measured without a highly invasive operation. The integration of the GM-model to the AMS therefore leads to further insight in intrinsic foot muscle forces and the accessibility to the model for a large group of users.

The GM-model in the production chain for rapid manufacturing of foot orthoses

Up to 196 million Europeans suffer disabling foot and ankle pain and the prevalence is set to rise in an ageing society with increasing chronic long term conditions. A conservative treatment to reduce foot and ankle pain is the use of foot orthoses (FO's). Currently 70% of the FO's produced yearly are made using traditional techniques relying on impressions casts, templates and hand fabrication. Personalised devices provide more effective outcome in terms of symptom reduction, fit, comfort and aesthetics but are more costly and time consuming to manufacture [10, 11].

The study presented in this thesis has been performed in the A-footprint project (http://www.afootprint.eu/), a European project funded under the FP7 program. A-footprint has the objective to develop novel ankle/foot and foot orthoses for common disabling conditions which are cost effective, high-speed to market, and personalised for form and function. With the use of novel scanning methods and models, a foot orthosis is designed and with rapid manufacturing the orthosis is 3D printed (see Figure 7.2)

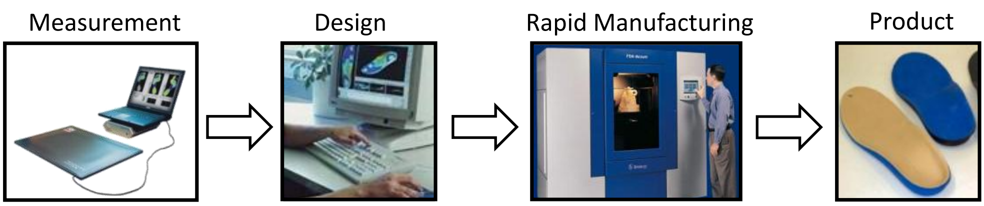

Figure 7.2 Visual representation of the novel production chain, as investigated in the A-footprint project. From dynamic measurements, via automatic design, the foot orthosis is rapid manufactured

The novel production chain starts with a dynamic plantar pressure measurement and a 3D surface scan of the foot and ankle. These measurements are used to scale (the 3D scan) the inverse dynamic musculoskeletal GM-model and dynamically drives this model with the dynamic plantar pressure scan. The inverse dynamic model can be used as an input in a forward dynamic model [12], as described in Chapter 1. The forward dynamic model is able to automatically design the shape and best material of a foot orthosis. Last step in this production chain is the rapid manufacturing of the designed FO.

This production method creates the ability to create personalised FO's that are designed and produced by a controlled and standardised method. And therefore, in the future the novel method will produce FO's cheaper, more precise. Furthermore, The FO's can be reproduced exactly or first adapted on a computer and then reproduced.

Conclusions

The work described in this thesis has already shown its added value by the embedding in the AnyBody Modelling System. Added value of the direct application of the GM-model, requires further research towards validation of the GM-model as described in Chapter 6. In addition, before the GM-model will be used in the production chain of rapid manufactured FO's further development of the coupling of the inverse dynamic model and the forward dynamic model is required.

Valorisation

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