XVII International Symposium on Computer Simulation in Biomechanics
July 28th – 30th 2019, Alberta, Canada

A CLINICALLY APPLICABLE PATIENT-SPECIFIC SURGICAL SIMULATION PLATFORM FOR FOOT AND ANKLE SURGERY: A FEASIBILITY STUDY

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INTRODUCTION

In orthopaedic surgeries, evaluation and treatment planning are highly based on empirical evidence and clinical expertise of each surgeon. The results of current surgical treatment approach remain suboptimal and don't guarantee the resolution of the patient's symptoms. Furthermore, inter-subject anatomical variation is hardly considered in decision-making. Therefore, a clinically applicable patient-specific simulation platform for foot and ankle surgery is in demand. With the development of computation capacities, numeric simulations thus began to show great potential in revealing subsurface mechanism inside foot, especially in view of the anatomic complexity of foot and ankle (26 bones, 34 synovial joints, hundreds of ligaments and muscles) and technical limitations of current external measurement systems. [1] This work presents a workflow integrating clinically-oriented data and a forward dynamic gait simulation combining a multi-body model (lower members) with a finite element model (tibia, fibula and foot).

As the complete platform is still under construction, this study aimed to explore preliminarily the biomechanical effect of supramalleolar osteotomies on the entire foot and ankle with the platform.

METHODS

Bones was segmented based on CT-scan of a healthy subject's right leg (unloaded condition). Soft tissue (skin, heel pad, plantar pad, filler) was segmented based on literature imaging data. Both segmentations were processed using ScanIP (Simpleware, UK).

Gait analysis (barefoot) was performed on the subject using an advanced clinical examination platform. Kinematics (with 42 retro-reflective skin markers detected by motion capture system), kinetics (ground reaction force (GRF), plantar pressure measurements (PPM)), and surface EMG of lower limb muscles were measured simultaneously during the experiment. A 3D multi-body (MB) model with 23 degrees of freedom (DoFs) was created in Simpack (Dassault Systèmes, France) based on CT-scan and MRI of the subject. It includes all intrinsic foot joints, 9 extrinsic foot muscles (Tibialis Anterior/Posterior, Peroneus Brevis/Longus, Achilles tendon, Extensor/Flexor Hallucis Longus, Extensor/Flexor Digitorum Longus) and all foot ligaments. DoFs allowed per joint were based on previous kinematic 3D multi-segment foot models and results of bone pine studies. Orientation of foot from pro-active phase obtained in experiment was used as initial condition. A forward dynamic gait simulation was generated using Simpack and optimized using Isight (Dassault Systèmes, France) to reconstruct the patient-specific muscular activation scheme.

With all the aforementioned information as inputs, a finite element (FE) model was automatically generated with an in-house Python script using Abaqus (Dassault Systèmes, France). Ligaments and tendons are modelled as 1D connectors, whose insertion and reflection point coordinates are determined by clinicians based on anatomical landmarks on CT-scan. The plantar fascia was represented by multiple connectors to evenly spread the loads. Material properties were based on values from the literature.

MB model was initially validated by comparing predicted and measured (via surface EMG) muscle timings. The error of the FE model was calculated as the difference between simulated and experimental gait data (PPM and GRF). The effect of simulated supramalleolar varus and valgus osteotomies on the entire foot was assessed by comparing tibiotalar joint pressure with literature results.

RESULTS AND DISCUSSION

The workflow was validated for the healthy subject from loading response to midstance through direct comparison between simulated gait variables and the coinciding experimentally measured ones. Fig. 1 shows that the simulated values of varus and valgus supramalleolar osteotomies matching the results of the cadaveric study qualitatively [2].

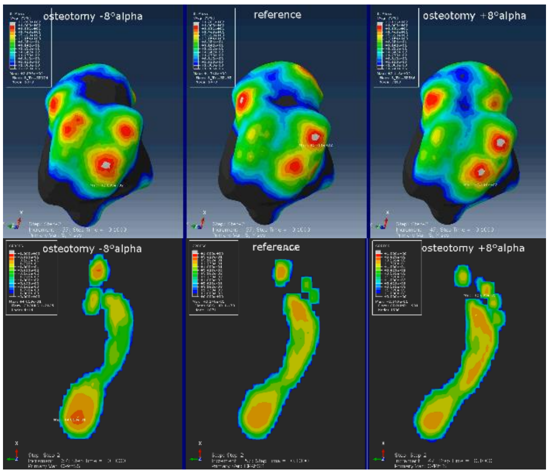

Fig 1: Stress over talar (above view) & plantar pressure

CONCLUSIONS

The proposed approach is deemed to have the potential to improve decision-making in evidence-based clinical practice for surgical treatment of foot and ankle pathologies.

REFERENCES

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2. Stufkens SA, et al. *J Bone Joint Surg* **93**: 1232-1239, 2011.