TLEMsafe: IMPROVING SAFETY AND PREDICTABILITY OF COMPLEX MUSCULOSKELETAL SURGERY USING A PATIENT-SPECIFIC NAVIGATION SYSTEM

1,2Marjolein van der Krogt, 1Vincenzo Carbone, 1René Fluit, 3Sjoerd Kolk, 1Bart Koopman and 1,4Nico Verdonschot
1Lab. of Biomechanical Engineering, University of Twente, Enschede, The Netherlands
2Dept. Rehabilitation Medicine, Research Institute MOVE, VU University Medical Center, Amsterdam
3Dept. Rehabilitation Medicine and 4Orthopedics Research Lab, Radboud University Nijmegen Medical Center, Nijmegen
email: m.m.vanderkrogt@utwente.nl, web: www.tlemsafe.eu

SUMMARY
TLEMsafe aims to develop a surgical navigation system based on patient-specific MR-based models, for training and pre-operative planning of complex musculoskeletal surgery. Here we describe the research setup of TLEMsafe, which we will illustrate using the results of a clinical example.

INTRODUCTION
The burden of musculoskeletal (MS) diseases and prosthetic revision operations is huge and is increasing rapidly with the aging population. For patients who require a major surgical intervention, procedures are unsafe, uncertain in outcome and have a high complication rate.

The TLEMsafe project aims to develop, validate and clinically implement an ICT-based patient-specific surgical navigation system (Fig. 1). The system uses image-based patient-specific musculoskeletal models. It helps the surgeon to safely reach the optimal functional result for patients that require complex musculoskeletal operations, and is a user-friendly training facility for surgeons.

In this paper we describe the research setup of TLEMsafe, which we will illustrate by presenting results of a clinical case example.

METHODS
Research outline
The starting point of TLEMsafe is the Twente Lower Extremity Model (TLEM) [1], implemented in the AnyBody Modelling Software [2] (Fig.2). This model and its underlying theoretical concepts undergo rigid validation using extensive measurements on healthy subjects. The model is made subject-specific using MR images and functional tests of healthy subjects and patients. Next, the surgery can be virtually performed on the patient-specific model. For this purpose, a user-friendly surgical navigation system is developed. Finally, the functional outcome of the virtual surgery on the model is compared to actual patient outcome.

Data collection
An extensive dataset is collected on healthy subjects for development and validation of subject-specific models. This dataset contains 3D kinematic, kinetic, and EMG recordings of a range of functional tasks, isometric and isokinetic strength tests of all joints of the lower extremities, MRI scans of the lower extremity to map musculoskeletal geometry, oxygen uptake during walking, and PET scans to quantify energy consumption by individual muscles.

A smaller set of data is collected on patients before and after complex musculoskeletal hip surgery. This dataset includes the functional tasks, strength tests, and MRI. The measurements allow the creation of patient-specific models and the exact quantification of the functional effect of the surgical intervention.

Image analysis
Since individual musculoskeletal characteristics may differ considerably between subjects, we develop and validate 3D image analysis techniques to distract important parameters to create 3D patient-specific models. Principle component analysis techniques are used to develop a (semi)-automated way to extract image parameters. Extracted parameters include bone geometry, muscle insertion sites and muscle volumes.

Computer simulation
Using the image and physical measurement derived parameters, TLEM is adapted to match the patient characteristics. The developed subject-specific models should predict a different functional outcome for each individual healthy subject. In addition, the model predictions should be concurrent with the measured parameters (e.g. glucose metabolism, oxygen consumption and EMG).
Simulating the surgery
The predictions of TLEM are mathematical and as such not directly useable by surgeons. Therefore, a pre- and post-processing facility is created which ‘hides’ the complex mathematical formulations and allows clinical interpretation of the results of the simulated surgical interventions for the surgeons. Using virtual reality algorithms, the surgeon can modify the MS model of his patient to simulate his operative plan. The module should allow 3D visualization and modification of the parameterized MS system of the patient.

Performing the surgery
A computer navigation module is developed that transfers the surgical plan as selected by the surgeon after performing an interactive surgical session on the MS model of his patient. This will ultimately allow the surgeon to perform the operation exactly as was found to be optimal in the pre-operative planning stage. The selected operative plan is fed into the navigation system to guide the surgeon through the surgery in a step-wise manner.

Post-surgery
The post-surgery measurements will be compared with the predictions of the patient-specific models in order to validate the model predictions. A difference is to be expected between model predictions and surgery outcomes due to the adaptive capacity of patients. This adaptive capacity that is until now missing in MS models will therefore be quantified and implemented.

RESULTS AND DISCUSSION
The patient considered here is a 41 year old female hip dysplasia patient, with a dysplastic right hip as shown in Fig.3. Functional tests show that the affected right leg of the subject is much weaker compared with the sound side, as illustrated for the knee extension torque in Fig.4. This asymmetry also shows during functional tasks such as rising from a chair, where the affected leg is loaded much less (Fig.5).

The MR images show the difference in muscle volume of the patient before surgery (Fig.6). This data is used to develop a pre-surgery patient-specific model, in which the surgery can be virtually performed (Fig.7).

CONCLUSIONS
TLEMsafe aims to develop a surgical navigation system, using image-based patient-specific musculoskeletal models. The presented case study shows the need for patient-specific models in case of complex musculoskeletal deformities. Using these patient-specific models, the surgery can be virtually performed and its effect on joint strength and functional tasks can be quantified. Comparison with post-operative measurements will be performed as a next step to validate these predictions.

ACKNOWLEDGEMENTS
The TLEMsafe project is funded by the European Commission FP7 programme. We acknowledge AnyBody Technology, Materialise NV, Warsaw University of Technology, and BrainLab, who as participants in TLEMsafe made an important contribution to this work.

REFERENCES