ISB 2013 BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS OF BIOMECHANICS

PATIENT-SPECIFIC MUSCULOSKELETAL MODELING OF HIP DYSPLASIA

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SUMMARY
Both the pre-op and post-op musculoskeletal geometry of a hip dysplasia patient was reconstructed semi-automatically using medical imaging data (MRI) and the surgery log. Gait lab measurements of the patient were performed pre-op as well as 12 months post-op. A pre- and post-op gait trial at comfortable walking speed was simulated using both a patient-specific and a scaled generic model. Differences in peak hip contact force of 97% were found between generic and patient-specific model. Furthermore, large differences in muscle activities were found between generic and patient-specific models and between pre- and post-op models. Although further validation is required, this seems to indicate that patient-specific models are essential to achieve realistic model outcomes.

INTRODUCTION
Developmental dysplasia of the hip (DDH) is a congenital or acquired misalignment of the hip joint (Figure 1A). Screening surveys suggests 1 to 1.5 cases of DDH per 1,000 newborns [1]. Hip replacement surgery (Figure 1B) is considered as a treatment for adolescents suffering from DDH in order to reduce joint pain and increase the quality of life. The largest difficulties during such a surgery are reconstructing the acetabulum at the correct anatomical position and determining the amount of femoral shortening to compensate leg length discrepancy.
One of the objectives of the EU-funded project TLEM*safe* is to predict the functional outcome on beforehand using musculoskeletal modeling. Exploring such a complex biomechanical problem requires accurate knowledge of lower limb muscle and joint reaction forces. Patient-specific models (Figure 1E, 1F) are expected to be more suitable for this purpose than scaled generic models (Figure 1C, 1D) [2] in order to achieve reliable predictions for individual patients [3]. One of the most sensitive model parameters are the muscle moment arms [4], of which the estimation depends on the identification of the musculoskeletal geometry and muscle-tendon paths.
In this study, we demonstrate a quick and semi-automatic method to generate patient-specific musculoskeletal geometries by morphing and registering a template model to the patient's MR images. The goal is to assess the differences between scaled generic models and patient-specific models based on pre- and post-op gait lab and MR measurements of a single patient suffering congenital DDH.

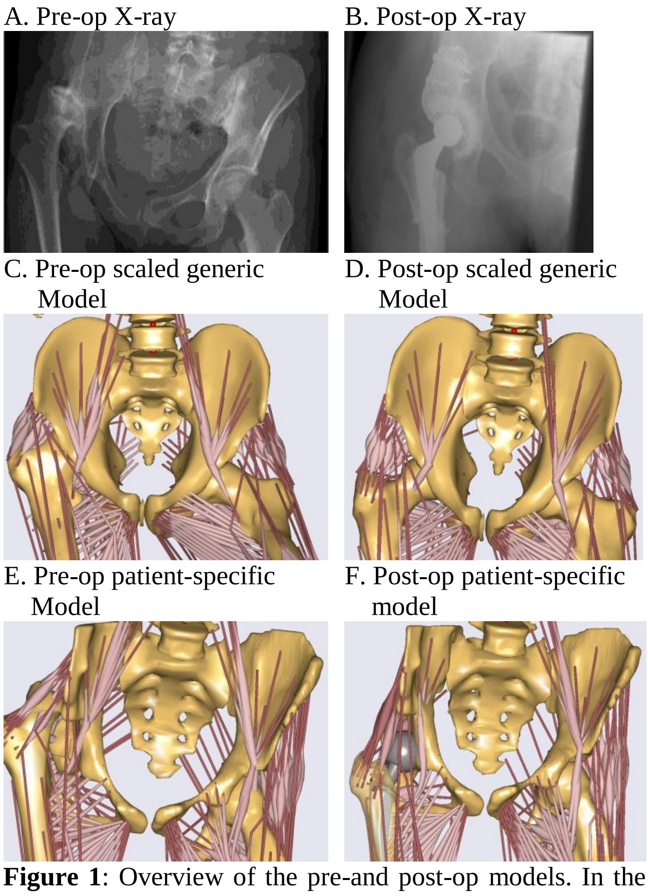

Figure 1: Overview of the pre-and post-op models. In the post-op models, the right hip joint is moved to the original acetabulum and the right Psoas and Gluteus Maximus are removed. In the patient-specific models, the skeletal geometry of the patient is taken into account. Visually, the patient-specific models resemble the X-ray much better than the scaled generic models.

METHODS
Gait lab measurements were performed both pre-op and 12 months post-op for a single DDH patient (F, 41 y, 179.5 m, 72.7 kg). A pre- and post-op comfortable walking trial was simulated with both a scaled generic model and the patient-

specific models using a musculoskeletal modeling tool (AnyBody 5.3, AnyBody Technology A/S, Aalborg, Denmark).
A pre-op MRI scan of the patient was made using a Siemens Magnetom 1.5T Skyra scanner. From the MRI, the bones of the lower extremity (pelvis, left and right femur and tibia) were segmented into STL-files using Mimics 15.01 (Materialise NV, Leuven, Belgium).
A pre-op patient-specific model (Figure 1E) was built by morphing each bone of a cadaver atlas [5] to the patient bones using non-linear morphing techniques (Materialise NV, Leuven, Belgium). This method assured that all muscle attachment sites were located on the bony contour. Using the same morphing technique, the hip, knee and ankle joint center were determined. The knee joint direction was optimized using a gait trial.
A post-op patient-specific model (Figure 1F) was built by performing a virtual surgery on the pre-op patient-specific model based on the surgery log: the right Psoas and Gluteus Maximus were removed (latter one was released from the femur during the surgery, but removed in the model), the right femur was shortened by 1.5 cm, a hip prosthesis was implemented and it's center of rotation was moved to the original acetabulum. The position of acetabulum was estimated with the morphing method.

RESULTS AND DISCUSSION

The predicted peak joint reaction force at the right hip (RHF) was 97% higher in the pre-op patient specific model than the pre-op generic model (Figure 2). High hip contact force may indicate the development of osteoarthritis [6] and may be a decisive factor for performing a surgery. If patient-specific models are used for surgery decisions, further validation of the patient-specific models is required.
The post-op RHF shows a similar shape as known from measurements of hip contact forces with instrumented implants [7], but slightly higher in magnitude. This indicates that the patient has adopted a near normal walking pattern, which was confirmed when comparing the post-op joint angles and moments with a healthy cohort (results not shown).
All 4 models predicted muscle activities below the maximum of 100 percent for all muscles in the affected leg. However, substantial differences were found in muscle activity predictions between generic scaled models and patient-specific models (Figure 3). Predicted peak activity of the Gluteus Medius was 457% and 74% higher in the patient specific than in the generic scaled model, for the pre- and post-op situation respectively.
Generally, the differences between model outcomes between generic scaled models and patient-specific models were larger for the pre-op situation than the post-op situation. This indicates the necessity of subject-specific models especially for patient cases.
Future work will focus on further personalizing the model by adding patient-specific muscle volumes using registration of the segmented muscle volumes from the cadaver template [5] to the patient's MRI.
Furthermore, for a true prediction of the functional outcome after a surgical intervention on beforehand, we aim to use model-predictive kinematics instead of measured post-op kinematics from a gait lab.

Validation of the patient-specific model is of key importance. Future research will address this by comparing the model-predicted muscle activities with EMG measurements and PET scans, which provide information about metabolic activity.

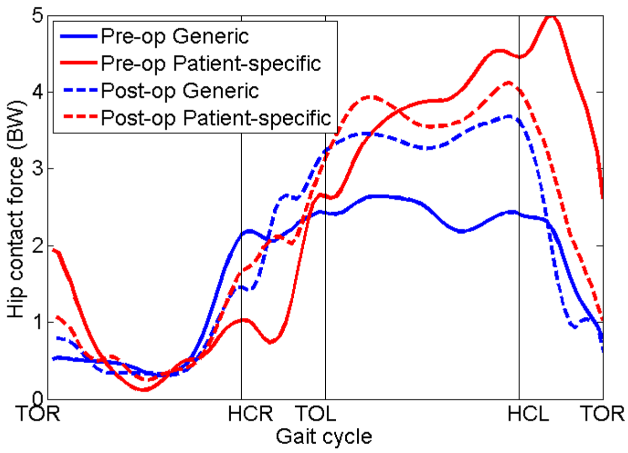

Figure 2: Predicted joint reaction forces of the right hip

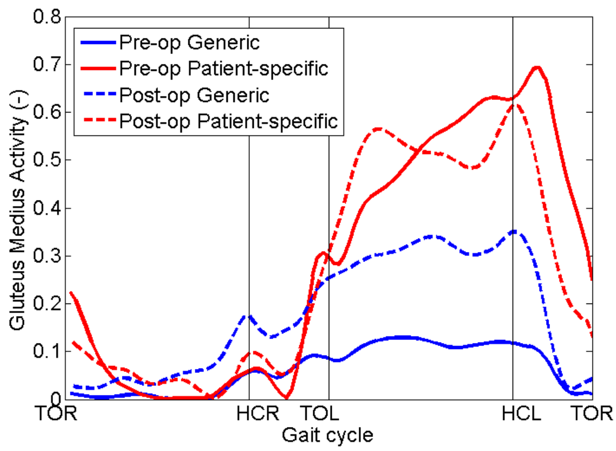

Figure 3: Predicted activity of the right Gluteus Medius

CONCLUSIONS

Large differences were found in model outcomes between a generic scaled model and a subject-specific model of a patient suffering from DDH. The differences were larger for the pre-op situation than the post-op situation. Although further validation is required, this seems to indicate that patient-specific models are essential to achieve realistic model outcomes.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the financial support provided by the European Commission FP7 Programme for the TLEM*safe* project.

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