VALIDATION OF A DIGITAL TWIN TO QUANTIFY THE LEVEL OF MOTOR CONTROL SUBOPTIMALITY IN PATIENTS

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Introduction

Neuro-musculoskeletal (NMSK) models, personalized and informed by experimental data, enable to predict internal biomechanical quantities which may have high informative value but that are difficult to measure *in vivo*. Motor control strategies that deviate from the so-called optimal control (e.g. a solution that minimizes the metabolic cost or energy expenditure) may further emerge, which may not be observed otherwise. Hence, we developed a Digital Twin in Healthcare (DTH), named JointForce, which we intend to position as a tool to quantify the level of suboptimality in a patient's motor control. In first instance, JointForce models will be used to predict joint contact forces (JCF) using various approaches, i.e., classical static optimization (hypothesizing optimal muscle control) and EMG-assisted approach [1]. Before the JointForce DTH can be employed to assist clinical decision making, it requires to undergo proper validation. In this work we present a first validation of JointForce models, and their predictions, against the recording of instrumented knee implants from a public dataset [2].

Methods

Experimental data from the last four editions of the Knee Grand Challenge (KGC) [2] were employed in this study. Image-based MSK models were generated using an in-house pipeline that exploits the STAPLE toolbox [3] and nmsBuilder [4]. Muscle points extracted from a generic template [5] were mapped onto the reconstructed bony geometries and minimally adjusted in accordance with medical images. Muscle properties were scaled and tuned to ensure physiological muscle behaviour [6], or personalized with information from available experimental data (e.g., maximal isometric forces scaled with the physiological cross-sectional areas outlined on the images). Biomechanical simulations of level walking were performed in OpenSim (standard workflow, from inverse kinematics to static optimization) and CEINMS (EMG-assisted approach, following model calibration). Predicted knee JCFs were compared to the corresponding *in vivo* measurements in terms of RMSE and R^2. Statistical significance, between JCF profiles, was computed using Statistical Parametrical Mapping ($\alpha = 0.05$).

Results

We hereby report the preliminary results on data from the 6th KGC (Figure 1). The static optimization approach produced estimates that more closely approximated the implant data (RMSE=0.42±0.1BW), compared to predictions resulting from the EMG-assisted approach (RMSE=0.88±0.06BW). However, the opposite was observed in terms of JCF profile similarity (R^2=0.89±0.05 for static optimization, R^2=0.91±0.03 for EMG-assisted approach).

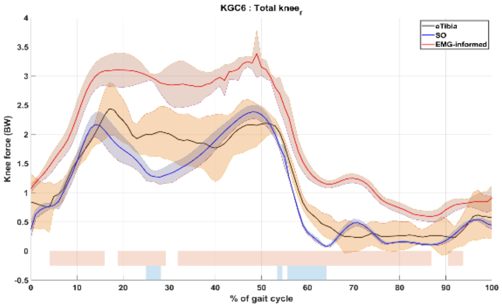

Figure 1: Knee joint contact forces predicted by the JointForce DTH, employing different approaches. Results are expressed in body weight (BW) and reported as mean and standard deviation across trials. In vivo recordings from an instrumented knee implant are reported for comparisons. Bars represent statistical significance ($p<0.05$).

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Discussion

These first results are encouraging, although the overestimation associated to the use of the EMG-assisted approach requires further evaluation. The JointForce DTH is currently under validation using data from the other three editions of the KGC [2]. We expect to complete the validation in the next few weeks. Once the JointForce DTH is validated, we will identify a system (e.g., an index) to quantify the degree of neuromuscular suboptimality in a patient, based on the distance between the optimal solution (obtained via a static optimization) and the EMG-assisted solution.

References

1. Pizzolato et al, J Biomech, 48:3929-3936, 2015.
2. Fregly et al, J Orthop Res, 30:503-513, 2012.
3. Modenese and Renault, J. Biomech, 116:110-186, 2021
4. Valente et al, C. Meth. & Prg. in Biomed, 152 85-92, 2014
5. Rajagopal et al, IEEE T. Biomed. Eng, 63:2068-2079, 2016
6. Modenese et al, J. Biomech, 49:141-148, 2016

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