A PROBABILISTIC ANALYSIS OF THE EFFECTS OF SOFT TISSUE ARTEFACTS ON THE ESTIMATE OF MUSCLE AND JOINT FORCES

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Introduction

Musculoskeletal models (MSMs), embedding multi-body optimisation algorithms, are used to predict joint kinematics and forces. Such predictions have proven to be more influenced by the soft tissue artefact (STA) than by other sources of uncertainties. However, the effects of STA on the estimates of muscle and joint forces are still unclear. The aim of this study is to investigate these effects for three commonly used OpenSim (https://simtk.org) MSMs.

Methods

Thirty-four 8mm-diameter reflective markers were attached to the feet (8), shanks (8), thighs (8), pelvis (4) and torso (6) of a healthy volunteer (male, 28 years old, 190 cm height, 82 kg mass). Marker trajectories (Vicon Ltd, UK) and ground reaction forces at both feet (Bertec Co.,USA) were recorded during static posture and level walking at self-selected speed. Three different lower-limb MSMs (ALLM [1], G2392 [2] and LLLM [3]) were scaled using OpenSim to match the subject's anthropometry and used to determine the pose of the bone anatomical frames. Reference joint angles were calculated using the OpenSim "*inverse kinematics*" tool. These angles were considered as representative of a young population, being within reported normality ranges [1]. The instantaneous global coordinates of the markers assumed rigidly attached to the model body segments were calculated using the "*point kinematics*" tool with the reference joint angles and marker local coordinates. These marker global coordinates were used as error-free reference datasets. STAs for the feet, shanks, lateral femoral epicondyles and pelvis markers were modelled as sinusoidal functions of the gait-cycle [4]. STAs for the lateral-thigh markers were modelled as a linear function of hip flexion, abduction, rotation and knee flexion angles [5]. The mean and standard deviation of the parameters defining the two STA models were taken from the literature [4,5] for each marker and spatial local coordinate, resulting in 324 variables for ALLM and G2392 and 162 variables for LLLM. Latin Hypercube Sampling was used to generate 500 samples for each stochastic variable. The corresponding 500 STA realizations were represented in the global coordinate system and added to the reference marker trajectories to obtain the artefact-affected trajectories. Joint angles, moments, and muscle and joint forces were estimated for the artefact-affected datasets using the OpenSim's built-in pipeline namely, "*inverse kinematics*", "*inverse dynamics*", "*static optimization*" and "*joint reaction analysis*". Knee forces for ALLM and LLLM were not investigated since they cannot be calculated using the latter tool. The variation of the muscle and joint forces output datasets was quantified over the entire gait cycle using the maximum of the differences between the 95th and 5th percentile of their values (normalised to the participant's body weight (BW).

Results

Average peaks of the generated STAs, computed for each marker over the 500 samples, were 39.7 ± 17.6 mm at the thigh and 11.9 ± 3.8 mm at the shank, consistently with the literature [6]. The highest muscle force variations were observed at the soleus, with values up to 1.4 BW for ALLM (Figure 1). Joint force variations increased moving from ankle to hip, where they were higher than 1.5 BW for all MSMs. Comparing the three MSMs against each other, differences between 0.2 and 0.1 BW were observed for the hip and ankle joint forces, respectively, and between 0.3 BW and 0.4 BW for the muscle forces.

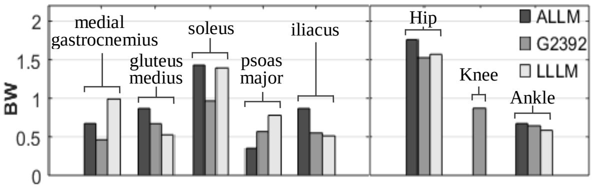

Figure 1: Selected muscle and joint force variations.

Discussion

The propagation of the STA to the estimate of joint forces was similar across the analysed MSMs while higher differences were observed for the muscle forces. Overall variations were within 0.5 and 1.8 BW, requiring further research in STA compensation, particularly at the hip, and/or experimental procedures to more accurately track human bone motion.

References

1. Arnold, E. M., et al., J Exp Biol, 216:2150-60, 2013
2. Delp, S., et al., IEEE Trans Biomed Eng, 37:757-67, 1990
3. Modenese, L., et al., J Biomech, 44: 2185–93, 2011
4. Chèze, L., et al., J. Biomech, 28:879-884, 1995
5. Bonci, T., et al., J. Biomech, 47:2354-61, 2014
6. Cappozzo, A., et al., Clin. Biomech, 11:90-100, 1996

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