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A joint kinematics driven model of the pelvic soft tissue artefact

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ABSTRACT

When skin-markers trajectories are used in human movement analysis, compensating for their relative movement with respect to the underlying bone (soft tissue artefact, STA) is essential for accurate bone-pose estimation; information about the artefact is required in the form of a mathematical model. Such model, not available for pelvic artefacts, could allow pelvic STA compensation in routine gait analysis by embedding it in skeletal kinematics estimators and developing *ad-hoc* optimization problems for the estimate of subject-specific model parameters. It was developed as driven by adjacent body segment kinematics. Model architecture feasibility was tested; its compensation effectiveness was assessed evaluating the error in pelvic orientation after removing the modelled artefact from the measured one. Five volunteers with a wide body mass range (BMI: 22–37) underwent MRI scans to reconstruct subject-specific pelvic digital bone models. Multiple anatomical calibrations performed in different static postures, as occurring during walking and star-arc movements, registering the bone-models with points digitized through stereophotogrammetry over pelvic bony prominences, allowed to define the relevant poses of a pelvis-embedded anatomical coordinate system. Such approach allowed to measure STAs over several pelvic anatomical landmarks, for each posture and subject. Model parameters were estimated by minimizing the least squares difference between measured and modelled STAs. The measured STAs were appropriately modelled with subject-specific calibrations, both in terms of shape (correlation coefficient: median [inter-quartile-range]: 0.72 [0.36]) and amplitude (root mean square residual: 3.0 [3.2] mm). Consequently, the overall error in pelvic orientation vector (5.1 [4.4] deg) was reduced after removing the modelled artefacts (2.5 [1.9] deg).

1. Introduction

The movement between markers attached on the skin, as used in stereophotogrammetry for human movement analysis, and the underlying bone (soft tissue artefact: STA) has been investigated in various body segments and during different motor tasks (Cereatti et al., 2017). This phenomenon and its detrimental effects on the determination of bone pose during dynamic movements has been acknowledged as critical for human movement analysis (Baker, 2006; Leardini et al., 2005; Peters et al, 2010). Therefore, appropriate algorithms are necessary to minimize the effects of STA propagation for the estimation of bone pose of all body segments or of a joint centre, as is the case for thigh and pelvic STA propagation to the hip joint centre estimation, or axis of rotation, as is the case for thigh and shank STA propagation to the knee axis of rotation estimation, or joint kinematics (skeletal kinematics optimal estimator). The development and assessment of the above-mentioned algorithms requires information about the artefact, in the form of a mathematical model (Bélaise et al., 2016; Bonci et al., 2014; Camomilla et al., 2009, 2013, 2015; Cereatti et al., 2006).

There is wide consensus on the fact that STA, caused by a combination of skin stretching and sliding, muscle contraction, gravity and inertia, is unique to each specific body segment and marker location, subject, and motor task performed (Akbarshahi et al, 2010; Leardini et al, 2005; Peters et al, 2010). However, it has been shown that some general features may be identified. For instance, for motor tasks that do not involve high accelerations or impacts, and tasks performed by non-obese volunteers, the largest proportion of the STA affecting markers located on a given body segment is closely correlated with the relevant joint movement (Bonci et al., 2014; Camomilla et al., 2013, 2015; Cappozzo et al., 1996; De Groote et al., 2008). This circumstance has allowed the formulation

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