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The SCoRE residual: A quality index to assess the accuracy of joint estimations

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ABSTRACT

The determination of an accurate centre of rotation (CoR) from skin markers is essential for the assessment of abnormal gait patterns in clinical gait analysis. Despite the many functional approaches to estimate CoRs, no non-invasive analytical determination of the error in the reconstructed joint location is currently available. The purpose of this study was therefore to verify the residual of the symmetrical centre of rotation estimation (SCoRE) as a reliable indirect measure of the error of the computed joint centre.

To evaluate the SCoRE residual, numerical simulations were performed to evaluate CoR estimations at different ranges of joint motion. A statistical model was developed and used to determine the theoretical relationships among the SCoRE residual, the magnitude of the skin marker artefact, the corrections to the marker positions, and the error of the CoR estimations to the known centre of rotation. We found that the equation $err = 0.5r_s$ provides a reliable relationship among the CoR error, *err*, and the scaled SCoRE residual, r_s, providing that any skin marker artefact is first minimised using the optimal common shape technique (OCST). Measurements on six healthy volunteers showed a reduction of SCoRE residual from 11 to below 6 mm and therefore demonstrated consistency of the theoretical considerations and numerical simulations with the *in vivo* data.

This study also demonstrates the significant benefit of the OCST for reducing skin marker artefact and thus for predicting the accuracy of determining joint centre positions in functional gait analysis. For the first time, this understanding of the SCoRE residual allows a measure of error in the non-invasive assessment of joint centres. This measure now enables a rapid assessment of the accuracy of the CoR as well as an estimation of the reproducibility and repeatability of skeletal motion patterns.

1. Introduction

The accurate quantification of skeletal motion is not only important for the assessment of abnormal gait patterns caused by skeletal disorders such as cerebral palsy (Röhrle et al., 1987; Bowsher et al., 1993), but also plays a key role in predicting musculoskeletal loading (Heller et al., 2001, 2003; Taylor et al., 2004, 2006) and the functional evaluation of therapy outcomes (Cappozzo, 1983). Marker-based motion capture has therefore become a common approach for the collection of kinematic data (Leardini et al., 1999), with clinical applications focused on using skin markers to derive internal bone motion (Benoit et al., 2005; Stagni et al., 2005). The reconstruction of skeletal kinematics, however, is limited by the relative motion of the skin markers over the underlying bones (Cappozzo et al., 1990), an error referred to as soft tissue artefact (STA).

In order to reduce the errors in determining skeletal kinematics caused by this soft tissue artefact, a number of numerical approaches have been presented (Andriacchi et al., 1998; Lu and O'Connor, 1998; Cappello et al., 2005). By generating a rigid marker configuration from the complete segment marker data, the optimal common shape technique (OCST) (Taylor et al., 2005) removes any motion of the markers relative to one another—an artefact generally associated with muscle firing and skin elasticity. The advantages of this approach have been demonstrated directly against skeletal motion using bone pin data in sheep, but how these findings relate to the conditions in humans remains unknown because the assessment of segment and skeletal motion in sheep was restricted by the limited range of joint motion during normal gait and the magnitude of skin marker artefact. Whether, and to what extent, application of the OCST improves

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