INTRODUCTION

The assessment of kinematics and kinetics of the lower limb provides quantitative measures of functional deficits in patients throughout diagnosis, treatment and monitoring of musculoskeletal disorders. While such biomechanical data therefore offer objective information for understanding disease mechanisms and directing treatment, its applicability depends crucially on the accurate determination of the motion of the skeletal structures. Recently, so called functional procedures have been introduced that use multiple markers to track limb motion together with dedicated mathematical algorithms to enable the accurate determination of joint centres and axes from motion data [1,2]. However, gait patterns assessed using markers placed on the skin are generally susceptible to soft tissue artefacts (STAs), errors that originate from skin elasticity and the synchronous shifting of the soft tissues over the underlying bones. The magnitude of each marker artefact, however, is known to vary according to its placement [3]. However, no recommendations are available that describe how a marker set that uses a larger cluster of individual markers per segment can be optimised to best allow the functional identification of the underlying skeletal joints. It was hypothesized that targeted marker placement using such information could allow for a considerable improvement in the reliability of skeletal kinematic assessment.

The aim of this study was therefore to interrogate the importance of each of a large number of skin markers in order determine the regions of the thigh most suitable for functional determination of the hip joint centre.

MATERIALS AND METHODS

Recently, methods to minimise the errors associated with skin marker artefact have been proposed using the Optimal Common Shape Technique (OCST) [4]. Here, the motion of skin markers relative to one another, and therefore the effects of skin elasticity, is minimised by generating a rigid configuration of the segment marker set, formed from all time points of the trial. In addition, accurate and robust methods to functionally determine spherical joint centres using the Symmetrical Centre of Rotation Estimation (SCoRE) [5] have been developed and verified in silico. Importantly, the residual of this SCoRE approach serves as an indirect measure of the accuracy of the SCoRE functionally identified joint centre [6]. In numerical simulations, it has been shown that the global error is linearly related to the SCoRE residual when no single marker artefacts are present i.e. conditions that are created with the use of the OCST.

The combination of the OCST and the SCoRE residual therefore allow the targeted weighting of each skin marker in a process that optimises the marker weights in order to minimise the SCoRE residual. The so called weighted Optimal Common Shape Technique (wOCST) therefore provides knowledge of the importance (or weight) of each marker for producing spherical joint motion, without the assumptions associated with generic anatomical relationships.

In this study, clusters of up to 72 retro-reflective markers were equally distributed on the skin of the right thigh and pelvis (Figure 1) of seven healthy subjects (age 29.1±5.5; BMI 22.1±1.3). All subjects provided written informed consent, and the study was approved by the local ethics committee. Motion analysis (Visom, UK) of a standardized star-arc movement [7] was performed, as well as a single recording of a static standing posture.

The wOCST approach was then applied to assess each marker's importance for defining a spherical hip joint centre. After the mean of all subject-specific marker weightings on the thigh were summed, the markers with the largest weights were selected and pooled into six regions of highest importance, with each region encompassing the 3 highest weights of that region. No regions of importance were determined for the pelvis in this study.

RESULTS

The SCoRE residual determined using all markers was 3.4 ± 0.6 mm, equivalent to an average error in the hip joint estimation of approximately 1.7 mm. Only 12.5% of the markers possessed a weight of over 0.04 (max. 1.0), and were located in 6 major cluster regions. The SCoRE residual determined from 20 different combinations of different marker sets did not differ (max. 1.0) from the six regions that were selected and without any anatomical landmarks was 4.2 mm ± 0.9 mm.

Figure 2: Areas of the thigh associated with highest markers weights, and thus important marker placement regions for the functional identification of the hip joint.

DISCUSSION

With this new approach, we have been able to target appropriate locations for the placement of skin markers by assessing their relative contribution to a spherical joint from functional kinematic data, thereby improving the reliability and accuracy of marker based motion capture. While this approach is based upon the assumption that a perfectly spherical joint between the pelvis and femur is coincident with the hip joint centre, further cadaveric studies are currently ongoing to confirm this supposition. However, through a clear reduction of the SCoRE residual from 5 markers alone, the motion of 6 targeted markers from the identified regions of high importance seems to be capable of determining a similar quality joint to that possible using the complete marker set tested.

The high weightings assigned to only few markers over the seven subjects appear to indicate that few well placed markers are able to contribute nearly all the most important information to the identification of the hip joint. The regions of markers with low weighting seemed to be clearly associated with e.g. the bellies of large muscles, which could be expected to generate higher levels of soft tissue artefact during the kinematic motion. Whether these regions remain consistent in subjects that are e.g. older or possess different levels of body fat or muscle remains to be investigated. The new approach presented here, however, provides a clear pathway to directly identify how the functional identification of skeletal joints can be optimised by the targeted placement of skin markers.

REFERENCES