A new approach for optimally reducing skin marker artifact allows determination of the hip joint center within 3 mm

1Kratzenstein, S; 2Heller, MO; 3Ehrig, RM; 4Wassilew, G; 5Duda, GN; 6Taylor, WR
7Julius Wolff Institute, Charité – Universitätsmedizin Berlin, Germany, 2Zuse Institute Berlin, Germany
bill.taylor@charite.de

INTRODUCTION:
Functional analysis has become an essential tool for differentiating between healthy and pathological movement patterns in clinical and sports science applications [1]. Here, skin marker based measurement approaches have achieved considerable accuracy and have thus become standard applications for collecting kinematic data. However, their accuracy is limited by soft tissue artefacts (STAs) that occur as the skin moves relative to the underlying skeletal structures. The Optimal Common Shape Technique (OCST) was developed to allow an effective reduction of single marker deviations from the movement of the entire cluster. However, this method assumes that all markers are equally affected by STAs and is unable to preferentially select markers that are less affected by motion artefact.

The Symmetrical Centre of Rotation Estimation (SCoRE) is an approach to optimally and accurately determine the centre of rotation (CoR) of spherical joints from functional data [2]. The mathematical residual of this approach has been recently identified as a reliable measure of the accuracy of the joint position through its correlation with the error in CoR position. It would therefore appear possible to exploit this residual to optimise the skin marker motions towards minimising the CoR error. By using this estimator of error in CoR position to extend the OCST such that markers can be weighted to minimize the SCoRE residual, we aimed to demonstrate that accounting for non-uniform distributions of STAs significantly improves the estimation of HJC in vivo.

METHODS:

Weighted OCST: The OCST constructs a marker configuration that fits optimally to the marker positions over all time frames, thus removing individual marker deviations. In a development of this technique, the weighted OCST (wOCST), weights are assigned to each marker that are optimized until the SCoRE residual is minimized, in order to determine the best possible rigid marker configuration. In this combined application of the wOCST together with the SCoRE technique, markers that are shown to contribute little to determining the joint center, such as those close to the joint or those that are more affected by STAs [3], are assigned a low weighting and thus have only a low impact on the definition of the final marker configuration.

In vivo application: 17 patients (aged 68.8±8.2; BMI 28.5±2.1, no self reported functional limitations and no signs of excessive PE wear were visible) were recruited at least 3yrs after total hip replacement. The subjects gave their written, informed consent to participate in this study, which was approved by the local ethic committee. Each subject was equipped with a set of at least 4 markers on the pelvis and 6 on the thigh and performed 3 repetitions of a star-arc motion [4], which was captured at 100Hz (VICOM3D, Oxford, UK). Hip joint center (HJC) positions were estimated using the SCoRE on the raw motion data as well as on data sets that were optimized by the application of either the classic OCST [5] or the wOCST.

Since determination of the HJC without the use of the OCST to construct a rigid configuration of the marker set is highly dependent upon the choice of markers, HJC calculations were performed using all possible combinations of marker triples on both segments. This allowed a fair comparison with HJC's calculated using the OCST. The quality of the HJC estimation was then assessed using the SCoRE residual, in order to acquire the true error of the reconstructed joint position.

RESULTS:
In each of the 17 subjects, the largest residuals and therefore largest HJC errors occurred when using the raw data alone (Ø10.2 mm SD 2.3). Application of the OCST reduced these values (Ø7.3 mm SD 2.1), while the lowest residuals and thus errors were achieved when analyzed using the wOCST (Ø3.8 mm SD 1.0). The application of the wOCST optimization achieved significantly lower residuals (Fig. 2) than residuals after classic OCST processing.

DISCUSSION:
Application of the OCST or the wOCST in the functional identification of the HJC's of 17 THA patients has resulted in an effective reduction of the SCoRE residual. These results agree with previous studies that investigated the benefit of STA reduction techniques [5]. Furthermore, this study has demonstrated that the consideration of marker weights in the wOCST leads to a further improvement over and above those achieved using the classic OCST.

While in vivo determination of the HJC is difficult in typical THA patients, who are often subject to a higher BMIs and thus susceptible to higher levels of STA, this study has successfully demonstrated that it is possible to accurately determine the HJC. Using a previously determined relationship that links the SCoRE residual with the CoR error, the average error in the HJC in these subjects was approximately 3mm.

Using robust and rapid optimization techniques, the wOCST has proved capable of differentiating between markers that are more or less affected by ST and is therefore able to determine the optimal configuration that accounts for individual marker impacts. In agreement with the findings of previous studies [3], markers in the proximity of the joint were generally assigned lower weights and therefore considered less important in the optimization process. The wOCST therefore has the ability to automatically deal with less optimally placed markers. The implementation of the weighting of skin markers in these subjects caused an average reduction of the SCoRE residual by approximately 3mm (Fig. 2).

Figure 1: Relative frequency of the SCoRE residuals for all possible (40,320) marker combinations of the raw data sets (exemplary shown for a single patient). The single residual values determined from the application of the OCST or wOCST are presented as vertical lines.

Figure 2: SCoRE residuals after optimization of data sets with OCST and wOCST, determined over all 17 THA

Functional determination of the hip joint center has been shown to be most accurate using the wOCST in combination with the SCoRE, with HJC errors for the first time consistently in the range of mm rather than cm. In conclusion, the results of this study demonstrate that estimations of the hip joint center in vivo can be effectively improved by accounting for non-uniform distributions of STAs as possible using the wOCST, even in THA patients with larger amounts of soft tissue coverage.

This study was partially supported by the DFG SFB 760

REFERENCES:
[3] Stagni et al., Clin Biomech, 2005
[5] Taylor et al., JOR, 2005

Paper No. 242 • 56th Annual Meeting of the Orthopaedic Research Society