EVALUATION OF FEMORAL HEAD REGISTRATION TECHNIQUE FROM EXTERNAL PELVIS MARKERS USING STEREORADIOGRAPHY

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INTRODUCTION

Accurate estimation of joint centers is essential in movement analysis. Particularly, joint centers are input data for kinetic calculations [1] providing articular forces and moments. To assess hip joint center, different methods are proposed in the literature that can be classified in three categories: predictive method [2], functional method [3, 4] or registration method. Registration method are based on the use of imaging to obtain the relationship between bones geometry (in particular joint centers) and external markers placed on the skin. Usually, these method are limited to small samples of subjects because they imply irradiant or/and expensive techniques. However, the use of a low dose bi-planar X-ray system (EOS Imaging – France) would allow performing these method in more extensive study. The images from this system can be used to reconstruct 3D bones geometries simultaneously with external markers. It is then possible to assess the relation between external markers embedded frames and bones structures. The aim of the present paper is to evaluate the accuracy of hip joint center registration from external pelvic markers using the EOS® low dose bi-planar X-ray system.

METHODS

Subjects

Ten young volunteers (6 males and 4 females) were considered after informed consent and ethical committee approval. The subjects were of various body mass indexes ranging from 17 to 28.

Protocol

The present study was part of a more complete work which aimed at validating a kinematical model from functional motions. So, the volunteers were equipped with reflective markers used for motion analysis with a VICON® system (Oxford Metrics – UK) and performed several knee and hip motions. In particular, four reflective markers were placed on the iliac spines of the pelvis. Then, for each subject, two pairs of images were taken with the EOS® system allowing to reconstruct at least pelvis markers and the right femoral head (Figure n°1). Due to EOS® acquisition requirements, subject positioning was standardized with knees extended and right foot anterior to the left one (the tip of the left great toe being approximately at the level of the base of the first right metatarsal). Markers were not removed between both acquisitions.

Evaluation of the repeatability of markers identification

To carry out the registration of the femoral head, a frame was embedded to the pelvis from 3D coordinates of the external markers. An evaluation of the repeatability of the identification of marker centers was conducted as an estimation of the accuracy of this identification. Data from 4 subjects were used (1 male and 1 female with a BMI > 25, 1 male and 1 female with a BMI < 25). Markers of pelvis from the first set of X-rays were considered. Markers were manually placed on the two sets of biplanar X-rays using the projected images of a 14mm-diameter sphere model. Four operators (bioengineers), two novice and two well trained independently placed three times the entire set of markers (72 markers for each subject). The method described by Gluer [5] was used to calculate the precision of placement with confidence interval at 95% for each operator (intra-operator repeatability), using the 72 markers and the 3 repetitions, and for all operators (inter-operator repeatability), using the 72 markers and one of the repetition of each operator (4 observations).

Evaluation of femoral head registration

Both sets of X-Rays showed all the markers of pelvis together with the right femoral head. Main difference in positioning between the two acquisitions is a slight shift to the right on the platform. Between the two acquisitions (5 min for the system to cool down), subjects were allowed to rest in a standing position outside the EOS system. The right femoral head could be identified in the two pairs of radiographs from the 3D reconstruction of the right femur. The femoral head and the markers were located on both radiographies, and their 3D coordinates were computed in the EOS reference frame. It was therefore possible to register the femoral head identified on the first sets of radiographs in the second pairs of radiographs and to calculate the distance from this registered femoral head with the femoral head identified directly on the second images. The registration was made using a svd algorithm [6] considering the set of markers as rigid.
RESULTS AND DISCUSSION
Intra-operator and inter-operator reliability was lower than 0.2 mm for each coordinates of the markers (in the EOS frame) for trained operators, while it could reach 0.4 mm when non trained operators are considered. The mean distance between the femoral head registered from pelvis markers and the femoral head computed from the femur model was 2.9 mm with a maximum of 4.2 mm (Table 1). Over the 10 subjects, only 3 had a registration error higher than 3.5 mm. There are very few studies evaluating the accuracy of femoral head assessment using imaging. Leardini [4] compared the centre of femoral head computed by predictive and functional method with the one obtained from stereoradiography. The best accuracy was found for functional method but the error had a mean value of 13 mm.

CONCLUSIONS
The proposed protocol allows assessing the best accuracy that could be expected for a femoral head registration from external pelvic markers. The value obtained can then be considered as a value of reference when evaluating other methods of determination of the center of the femoral head as predictive or functional methods.

ACKNOWLEDGEMENTS
The authors wish to acknowledge VICON® for their support.

Table 1: Pelvis markers based registration error for 10 subjects: Distance between femoral head (FH) registered from pelvis markers and FH computed from 3D model (mm)

<table>
<thead>
<tr>
<th>Subjects</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>Mean</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Error (mm)</td>
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<td>4.2</td>
<td>3.6</td>
<td>3.3</td>
<td>3.5</td>
<td>2.0</td>
<td>4.2</td>
<td>1.2</td>
<td>2.2</td>
<td>2.8</td>
<td>2.9</td>
<td>4.2</td>
</tr>
</tbody>
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