Analysis of Extreme Hip Motion in Professional Ballet Dancers

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Abstract—The aim of the present work is to analyze the consequences of repetitive extreme hip motion in professional ballet dancers. The motivation for this study is that dancers' activities can be at the origin of hip osteoarthritis. To verify this hypothesis, bone poses of patient-specific hip joint are obtained using an optical motion capture system, while soft tissue artifacts are reduced by applying a global minimization. Subsequently, collision detections are performed among the joint tissues during motion. Results show a strong correlation between the observed collisions and the diagnosed lesions. The estimation of the hip kinematics was successfully validated with data collected from a dynamic MRI protocol.

Keywords-hip joint; impingements; skin artifacts; extreme motion; dancing;

1. INTRODUCTION

Osteoarthritis affects the hip joint and is a common problem for many people. This pathogenesis can be caused by impingements (bone collisions). Changes in the movement and alignment of the hip also lead to excessive wear and tear on the joint surfaces. Therefore, do people practicing a sport requiring extreme movements present a higher risk of developing arthritis? To detect arthrogenous activities, a clinical study with 30 professional dancers is being conducted. Since repetitive extreme motion can be a factor of joint degeneration through joint subluxation and excessive labral deformations, the estimation and validation of femoroacetabular movements are important.

To derive the motion of the skeleton, various methods with direct access to the bone (e.g. intra-cortical pins, external fixators, percutaneous trackers) have been proposed. These techniques are robust, but are strongly invasive. Therefore, the optical motion capture system appears as a non-invasive solution for studying the kinematics of the joint, allowing the recording of a large range of motion. However, the major drawback of these systems is the soft tissue deformation due to muscle contractions. To minimize soft tissue artifacts (STA), mathematical approaches have been implemented [1-3], but these techniques do not perform better than traditional bone pose estimators [2], or are based on invalid assumptions [1] or are limited to the use of non subject-specific models (e.g. ball-and-socket joints) [3].

The aim of the present study is to analyze the consequences of repetitive extreme hip motion in professional ballet dancers. Bone poses of patient-specific hip joint are obtained using an optical motion capture system, while STA are minimized by applying a global minimization. Subsequently, collision detections are performed among the joint tissues during motion. The results of a preliminary investigation on 5 dancers are presented and compared with the radiological analysis of patients' magnetic resonance images (MRI). The estimation of the hip kinematics was successfully validated with data collected from a dynamic MRI protocol.

2. MATERIAL AND METHODS

Five professional female dancers were analyzed. The mean age, height and weight were respectively 20 years, 167 cm and 50 kg. The institutional medical-ethical committee approved the study and all subjects gave written informed consent. For each dancer, patient-specific 3D models (2 bones, 3 cartilages and a skin) of the hip joint were reconstructed from a static MRI protocol [4]. The same bone models were used to evaluate the hip joint centre's (HJC) position using a functional method, detailed in [5]. The pelvis and femoral coordinates' systems were implemented following the ISB recommendations [6].

Motion Recordings

Two clusters of six 7 mm spherical markers were affixed onto the lateral and frontal parts of both thighs. Six markers were also stuck on the pelvis (Fig. 1A). These skin markers were arranged to ensure their visibility to the cameras throughout the range of motion. Additional reflective markers were distributed over the body to confer a more complete visualization from general to detailed. Data from the subjects were acquired during dancing activities: lateral/ frontal split, developpé devant/ à la seconde, arabesque and grand plié. The markers trajectories were tracked within a 45.3 m3 measurement volume (3.6 x 4.2 x 3 m) using 8 infrared cameras (Vicon MX 13i, Oxford Metrics, UK), sampling at 120 Hz.

Subject Calibration

Before converting markers trajectories into animation, the skin markers must be replaced into the MRI space to establish a correspondence between the markers set-up and the segmented 3D models. Following motion recordings, the subjects underwent a 3D body scan (Vitus Pro, Vitronic, Germany) with the markers still in place to retrieve their exact external body surface. The positions of the skin markers were identified on the resulting body scan mesh using a least-squares sphere fitting technique. Finally, the body scan mesh was registered with the skin generated from MR images, performing the required calibration (Fig. 1A).

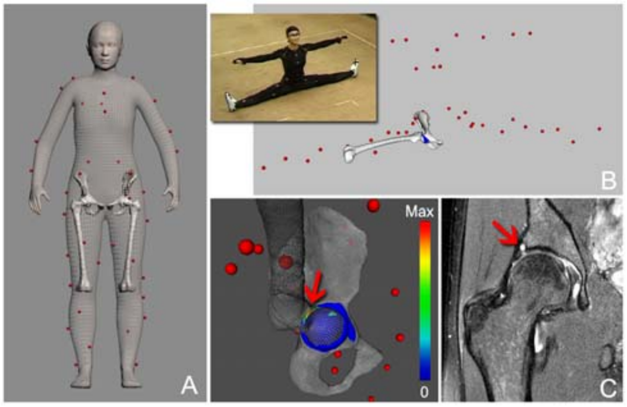

Figure 1. A) Calibrated subject showing the markers configuration with the reconstructed hip joints and the body scan mesh B) Example of real and computed postures (frontal split) C) Collisions during the frontal split (left) and diagnosed lesions (right) in subject #4. The labral collisions and the lesions are both located in the superior area of the acetabular rim (red arrows).

Bone Poses Estimation

Rigid motion of the bone segment cannot be robustly estimated from the markers trajectories, unless the STA is small. To reduce STA, we propose to use a global minimization that finds for each instant frame the rotation and translation that minimize the error made globally on all the markers. During a movement, several components contribute to the motion of a skin marker. Assuming that the pelvis motion is known, the HJC can slightly move during the rotation of the thigh. This introduces one translation T_c and one rotation R. Additionally, a rigid displacement is observed due to STA which is denoted by another translation T_s. The motion of a marker with respect to the pelvis can hence be described by 3 transformations successively applied. Since an accurate estimation of both T_c and T_s is hardly possible, one of the translations must be discarded. Previous works [7] showed that, for the thigh, the magnitude of the STA is greater than the displacement of the joint center. Therefore, we decided to compute the best estimate of T_s and to assume that T_c is close to null. On the contrary, for the pelvis, it appears that the STA remains small. Thus, for this bone we assumed that T_s is close to null and we estimated T_c instead. In order to find the transformation (3 unknowns for the rotation in an axis-angle form and 3 for the translation) that minimizes the error made globally on the markers, the objective function to minimize is as follows: $\sum_n(p_i\text{-}p'_i)^2$ with n the number of markers attached to the bone segment, p_i the recorded position of the i^{th} marker, and p'_i its estimated position. This is a least-squares minimization for which we used the rfsqp optimizer [8]. Since the skin markers move non-linearly, the solution converges faster by using a quadratic programming algorithm.

Validation

The validation of the hip kinematics estimation was obtained using marker position data, collected during clinical motion patterns (abd/ add, flex/ ext, in/ ex rot) on 6 volunteers scanned with a dynamic MRI protocol [9]. The subjects were equipped with external MRI-compatible marker sets and a tracking device was used to ensure the movements repeatability. For each instant frame, the position and orientation of both the hip and femur bones were computed. The kinematics derived from the marker position data were compared with that of the MRI bone tracking. Only the error on the femur translation/ orientation was calculated, since no markers were placed on the pelvis. The rms reconstruction error was 2.3/3.9/4.1 mm in femur x/y/z translation and 2.3/1.4/1.9 deg in femur orientation.

3. RESULTS

The patients' MR images were analyzed by radiological experts. For the 5 dancers, labral lesions were diagnosed in the superior or posterosuperior part of the acetabular rim. No morphological abnormalities were detected. To assess if repetitive extreme motion is at the origin of these lesions, the contact between the joint tissues (i.e. the cartilages and the bones) is simulated. While visualizing the subject's hip joint in motion (Fig. 1B), collision detections are performed among the joint tissues. Strong collisions were observed when the subjects were performing extreme hip flexions or abductions (e.g. split). The labral collisions were located in the superior area of the acetabular rim, which corresponds to the location of diagnosed lesions (Fig. 1C).

4. CONCLUSION

We presented a clinical application and a methodology for accurately estimating bone poses of patient-specific hip joint using an optical motion capture system. The analysis of professional ballet dancers in extreme postures confirms that repetitive extreme motion can be a factor of joint degeneration.

5. ACKNOWLEDGMENT

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