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A surface-based approach to determine key spatial parameters of the acetabulum in a standardized pelvic coordinate system

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ABSTRACT

Accurately determining the spatial relationship between the pelvis and acetabulum is challenging due to their inherently complex three-dimensional (3D) anatomy. A standardized 3D pelvic coordinate system (PCS) and the precise assessment of acetabular orientation would enable the relationship to be determined. We present a surface-based method to establish a reliable PCS and develop software for semi-automatic measurement of acetabular spatial parameters. Vertices on the acetabular rim were manually extracted as an eigenpoint set after 3D models were imported into the software. A reliable PCS consisting of the anterior pelvic plane, midsagittal pelvic plane, and transverse pelvic plane was then computed by iteration on mesh data. A spatial circle was fitted as a succinct description of the acetabular rim. Finally, a series of mutual spatial parameters between the pelvis and acetabulum were determined semi-automatically, including the center of rotation, radius, and acetabular orientation. Pelvic models were reconstructed based on high-resolution computed tomography images. Inter- and intra-rater correlations for measurements of mutual spatial parameters were almost perfect, showing our method affords very reproducible measurements. The approach will thus be useful for analyzing anatomic data and has potential applications for preoperative planning in individuals receiving total hip arthroplasty.

1. Introduction

Total hip arthroplasty (THA) is considered to be a successful treatment for patients with end-stage hip osteoarthritis [1]. Diseases and surgical procedures of the hip are inherently three-dimensional (3D), occurring in and around the proximal femur and the acetabulum. With the advent of cementless implants, the orientation of the femoral component must be consistent with the geometry of the femoral medullary cavity. Correct implantation of the acetabular component in THA is critical with respect to long-term survival as well as short-term complications [2].

Lewinnek et al. [3] proposed a safe zone for the placement of the acetabular component based on radiological analysis of the dislocation rates among 300 THAs. They recommended two related two-dimensional (2D) parameters for defining the safe zone, including an inclination of 40° (standard deviation [SD] 10°) and an anteversion of 15° (SD 10°) relative to the anterior pelvic plane (APP). This so-called safe zone is widely applied to guide the placement of the acetabular component, although the ranges for the inclination and anteversion remain unknown. The native orientation of the acetabulum or the transverse acetabular ligament [4] has also been used as guides, with satisfactory outcomes. However, the complex 3D geometry of the anatomic landmarks makes the determination and description of their orientations difficult [5,6], especially when the mutual relationship of the acetabulum and pelvis is considered. These complex anatomic structures do not allow for accurate measurement of their 3D orientations based on the 2D images provided by radiography or traditional axial tomography [7–13]. In addition to the orientation [14,15] of the acetabulum, other mutual spatial parameters, such as the center of rotation, remain unknown, despite their importance for successful hip joint reconstruction and the restoration of hip biomechanics [16]. Knowledge of these parameters will also benefit further biomechanical and anatomical research.

To further clarify the spatial relationship between the acetabulum and pelvis, and especially the acetabular orientation, a

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reliable pelvic coordinate system (PCS) is required [15,17–21]. A reliable PCS consisting of the APP, midsagittal pelvic plane (MSP), and transverse pelvic plane (TPP) is very important for the successful alignment of the acetabular component. The APP, a plane defined by the bilateral anterior superior iliac spines (ASIS) and the midpoint between the bilateral pubic tubercles, has the potential to be used to establish a reliable PCS. However, manual selection of these anatomic landmarks does not reliably define the APP. A surface-based approach has been proposed in [22,23] to overcome this drawback. By manually selecting both ASISs and pubic tubercles on partly homologous surface patches, the APP can be reliably computed by an iterative algorithm. The MSP and TPP can also be computed as the mirror plane associated with both ASIS regions by using an iterative closest point (ICP) algorithm. We hypothesize that a reliable PCS can be established from the APP, MSP, and TPP. Semi-automatically selected points on the osseous ridge of the acetabulum have been used to generate a best-fit circle for describing acetabular orientation [24]. Here we describe a novel method to measure the 3D acetabular orientation and center of rotation relative to the new PCS. The proposed method was recently used to study acetabular orientation statistics within a cohort of Chinese subjects [25]. In the present contribution, we describe in detail the technical aspects of the method, and investigate the intra- and inter-observer consistency of its results.

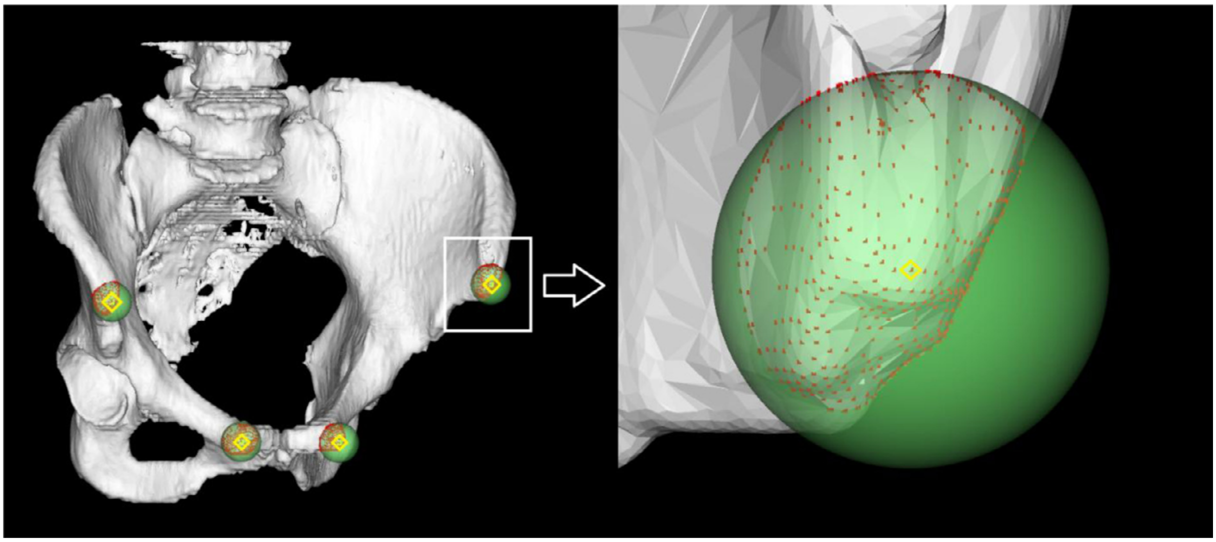

Fig. 1. Clipping landmark point sets on the pelvic surface. Four initial markers (yellow) are manually defined at positions near the landmarks. Point sets (red) are clipped using a spherical implicit function (green region; see Eq. (1)). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

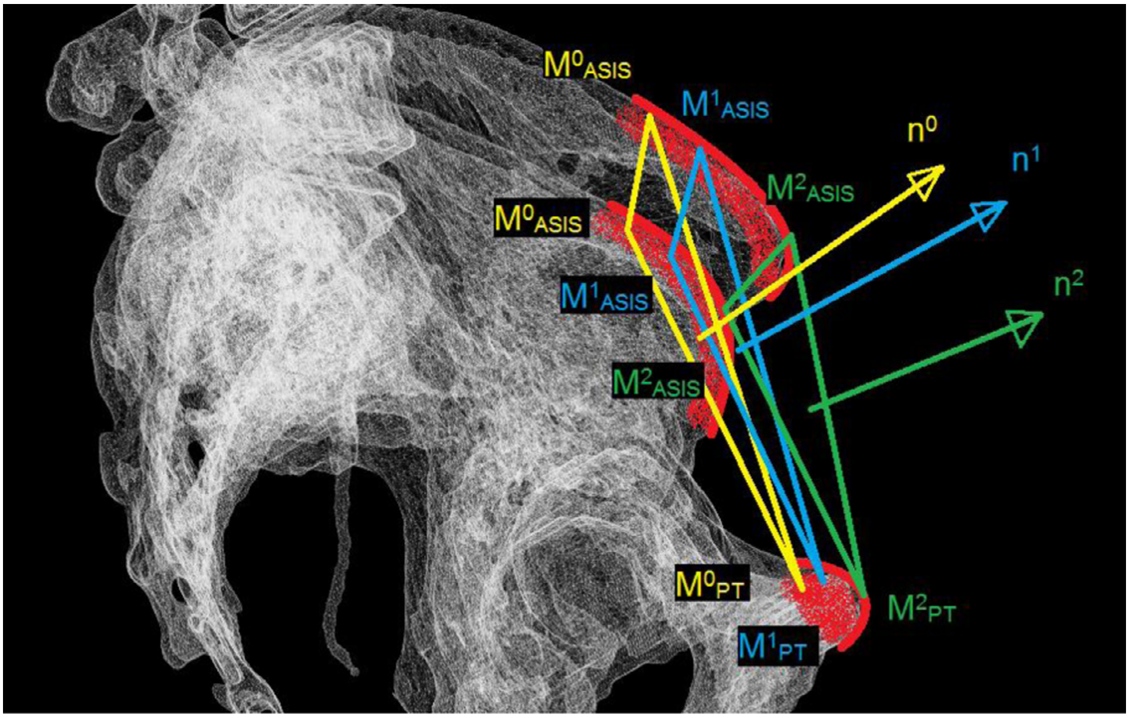

Fig. 2. Schematic diagram of the APP iteration. Automatically searching the most anterior point on the landmarks (red), markers are modified from M^0 to M^2(yellow → blue → green) within a few steps. The corresponding normal vector of the APP changes from $\mathbf{n}_0$ to $\mathbf{n}_2$. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

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