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Evaluation of automatic HJC definition

Luisa Berger[1], Kunihiko Tokunaga[2] and Klaus Radermacher[1]
[1] Chair of Medical Engineering, Helmholtz Institute for Biomedical Engineering, RWTH Aachen University, Aachen, 52074, Germany
[2] Niigata Hip Joint Center, Kameda Daiichi Hospital, Niigata City, 950-0165 Japan
berger@hia.rwth-aachen.de

Abstract

The hip joint center (HJC) does not only define the hip specific coordinate system in most definitions, but is also one of the most relevant functional parameters of the hip joint. Sphere fit of the femoral head is the most common method for HJC definition. In terms of preoperative planning for THA, many patients show deformities on the femoral heads and/or the acetabular region. Therefore, the approximation of the HJC via sphere fit has to be questioned. In our analysis, we studied different methods for automatic HJC definition and the influence of femoral head deformities on the location of the HJC for CT images of 201 THA patients. The different methods were ellipsoid fit on the femoral head, center of mass analysis of the femoral head, sphere fit on the acetabular region and geometric analysis based on ASIS location and pelvic width, height and depth. We compared the deviations between the sphere fit center and the different methods. We found best accordance with sphere fit for ellipsoid fit, followed by center of mass, acetabular sphere fit and geometric definition. The same tendency was found for the differences between sphere-like and deformed femoral heads, with deformed heads showing higher deviations for all methods. While no dynamic data was available, it has to be questioned, whether a sphere fit on the femoral head is the suitable for definition of HJC as center of rotation, especially for patients with deformed femoral heads. Further processing that takes different femur positions into account is recommended.

1 Introduction

Definition of hip joint center (HJC) is essential for analysis of hip morphology. The position of the hip joint center has influence on the kinematics of knee and hip, as well as on the moments acting on the hip joint [1,2]. In literature, cup wear and migration, calcar resorption and instability of the cup are mentioned as some of the consequences of incorrect positioning of the HJC [3,4]. A study from Karachalios et al. showed a significant correlation between the HJC and unfavorable long-term effects, such as cup wear and migration or calcar resorption for the cup placement [3]. While the definition as center of rotation is not applicable, when motion data is missing, the definition of the HJC based on

static information is needed [5,6]. In most literature, a sphere is used as approximation of the femoral head and the center of this sphere is used as HJC [7,8,9]. In the context of osteoarthritis and hip dysplasia many femoral heads show major deformities due to osteonecrosis and osteoarthritis. It has to be questioned, whether a sphere fit of the femoral head is the best approximation of the HJC in these cases. In literature more options are present for approximation of HJC [10,11]. In this study, we compared different methods of HJC definition to answer the question whether different methods provide a comparable hip joint center location. Furthermore, we analyzed the effect of femoral head deformity on the difference of HJC location.

2 Material & Methods

We analyzed an existing database of 201 Japanese patients that underwent unilateral primary THA, consisting of preoperative CT images. Segmentation was done following the approach described by Fischer et al. [7]. The meshes were analyzed in CT coordinate system, as our approach for a bone specific coordinate system of the hip relies on the definition of the HJC. The head region of the meshes was identified following the approach of Fischer et al. [12]. To all meshes, a sphere fit was applied to the femoral head ("femoral sphere"). Additionally, an ellipsoid was fitted ("femoral ellipsoid") and the mass center of the head region ("head center") was calculated on the femoral head. Furthermore, the center of the acetabulum was defined as center of a sphere fitted to the acetabular region ("acetabular sphere") and following Seidel et al. a geometric definition of the HJC ("geometric definition"), defined by the position of the ASIS and approximated by pelvis width, height and depth was applied from out the ASIS location [13]. For four patients, the analysis failed either due to failed determination of the head region or due to other computational problems. For all patients, visual inspection was done to check the determination of femoral sphere, ellipsoid and acetabular sphere. Nine patients were excluded after visual inspection, for all nine the acetabular sphere was positioned incorrectly. Of the remaining 188 femoral heads, 153 were classified as sphere-like and 35 as deformed by visual inspection.

As sphere fit to the femoral head is the most used method, this was defined as standard and the coordinates of the HJCs from the different methods were compared to the HJC of femoral sphere calculation.

3 Results

The geometric definition shows the highest deviation for all patient categories, while the femoral ellipsoid shows to be most consistent with femoral sphere. For all methods, the deviations are lower for the sphere-like heads compared to the deformed heads (Table 1).

Visual inspection showed that the femoral ellipsoid was not able to fit deformed femur heads better than the usual sphere fit (Figure 1 A, B). The acetabular sphere tended to be positioned more medially than the femoral sphere which can be explained by the deformity of the acetabular rim that forms the acetabulum to be more opened on the outside (Figure 1 C, D). The center of mass analysis of the femoral head showed to be in greater accordance with the HJC based on femoral sphere analysis than the center of the acetabular sphere, even for deformed femoral heads.

Table1: Deviation from femoral sphere center to the other methods

Method	Mean ± SD		
	All patients	Sphere-like femoral heads	Deformed femoral heads
Geometric	18.00 ± 7.72	16.79 ± 6.86	23.32 ± 8.90
Acetabular	5.29 ± 3.59	4.96 ± 3.27	6.77 ± 4.22
Head center	2.89 ± 1.64	2.62 ± 1.44	4.06 ± 1.93
Femoral ellipsoid	1.78 ± 0.14	1.77 ± 0.15	1.81 ± 0.12

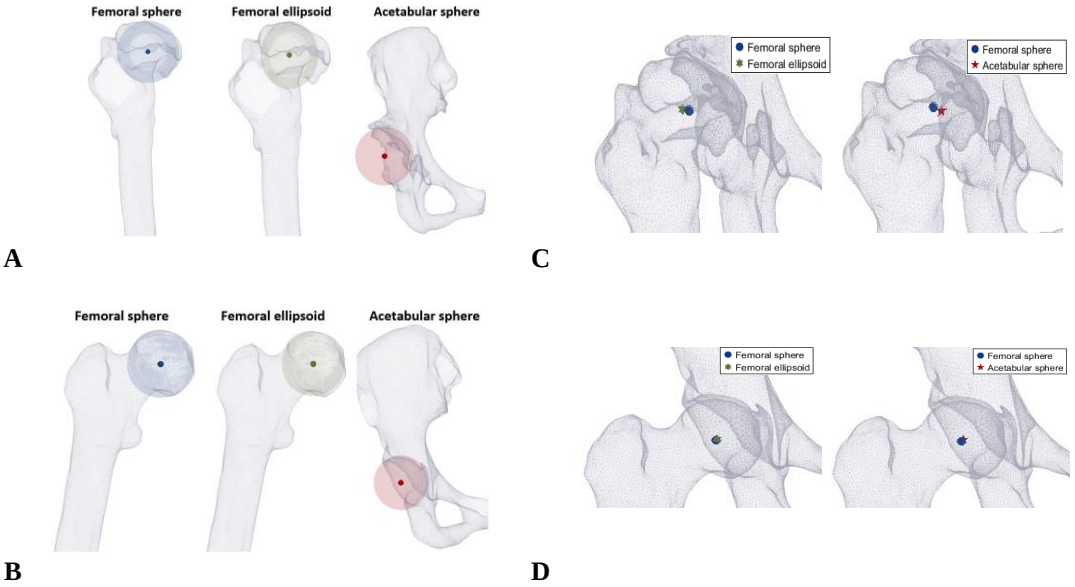

Figure 1: (A) Exemplary patient with deformed femoral head; **(B)** Exemplary patient with spheric femoral head; **(C)** Comparison between center of femoral sphere, femoral ellipsoid and acetabular sphere for an exemplary patient with deformed femoral head; (D) Comparison between center of femoral sphere, femoral ellipsoid and acetabular sphere for an exemplary patient with spheric head.

4 Discussion / Outlook

While being a valuable method for computing hip joint centre location in 3D in the 1990s and the early 2000s, the geometric definition had highest deviation from femoral sphere centre in our analysis. This result was expected as modern mesh processing tools are capable of individual morphological analysis and thus expected to increase the accuracy of HJC definition. The acetabular sphere shows more differences to the femoral sphere than the centre of mass of the head and the femoral ellipsoid, while it was expected to be more congruent with the femoral sphere as both bone parts perform together as a ball-and-socket joint. In our analysis, the differences between femoral and acetabular sphere were even higher than in the study from Hendriks et al. that found a mean directional distance of 3.89 mm between both sphere centres [11]. This could partially be explained by the fact that all of our patients were THA patients and thus mainly suffer from arthritic changes in the hip area, while Hendriks et al. analysed only patients with no signs of osteoarthritis. While the mass center of the head region always defines the midpoint of the entire femur head, this center of mass might not be the center of rotation. Our

analysis revealed, that the sphere fit is not always the method that represents the form of the femur head most accurate. However, as the hip functions as a ball-and-socket joint a rotational element is necessary. The center of mass might be not capable of representing the center of rotation. For ellipsoid fit, the HJC was less than two millimeters away from the sphere center, even for deformed femoral heads. As visual inspection revealed no better representation of the femur head for ellipsoid fit, no optimization could be seen compared to sphere fit analysis. All methods show more deviations for deformed femoral heads. Regarding THA surgery, offset was found to have influence on, for example, patient´s QoL, muscle and joint forces by offset variation of about 5 mm [14,15]. Excluding geometric analysis, the difference of the HJC location was between 2 mm and 7 mm which is on the range of variation in literature.
Especially for patients with osteoarthritis related deformities, defining the HJC based on a sphere fit of the head might be followed by a process to verify the location of the HJC with focus on rotational behaviour. A valuable approach might be based on the method from Kang, that modelled the HJC based on a conchoids shape fitting [10]. Also, typical deformities should be considered in HJC detection, as Hendriks et al. reported that the difference between femoral sphere centre and acetabular hemisphere centre was bigger for patients with hip dysplasia [12].

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