Cross-sectional Anatomy of Ilium for Guiding Acetabular Component Placement Using High Hip Center Technique in Asian Population

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Abstract

Background: Many clinical studies have been published involving the use of a high hip center (HHC), achieved good follow-up. However, there is a little anatomic guidance in the literature regarding the amount of bone stock available for initial implant coverage in this area of the ilium. The purpose of this study was to evaluate the thickness and width of the human ilium and related acetabular cup coverage for guiding acetabular component placement in HHC.
Methods: A total of 120 normal hips in 60 cases of adult patients from lower extremities computer tomographic angiography Digital Imaging and Communications in Medicine data were chosen for the study. After importing the data to the mimics software, we chose the cross sections every 5-mm increments from the rotational center of the hip to the cephalic of the ilium according the body sagittal axis, then we measured the thickness and width of the ilium for each cross section in axial plane, calculated the cup coverage at each chosen section.
Results: At the acetabular dome, the mean thickness and width of the ilium were 49.71 ± 4.88 mm and 38.92 ± 3.67 mm, respectively, whereas at 1 cm above the dome, decreased to 41.35 ± 5.13 and 31.13 ± 3.37 respectively, and 2 cm above the dome, decreased to 31.25 ± 4.04 and 26.65 ± 3.43, respectively. Acetabular cup averaged coverage for 40-, 50-, and 60-mm hemispheric shells, was 100%, 89%, and 44% at the acetabular dome, 100%, 43.7%, and 27.5% for 1 cm above the dome, and 37.5%, 21.9%, and 14.2% for 2 cm above the dome.
Conclusions: HHC reconstructions within 1 cm above the acetabular dome will be an acceptable and smaller diameter prosthesis would be better.

Key words: Anatomy; Hip; Ilium; Orthopedics; Total Hip Arthroplasty

Introduction

Reconstruction of acetabular components with a bone defect still challenges to orthopedic surgeons. Ideally, the acetabular component should be placed at the natural hip center as close as possible.[1-6] However, bone defect in those patients with development dysplasia of hip, acetabular migration superiorly followed by cup loosening, or severe periacetabular osteolysis, may prevent surgeon from placing the cup in a true anatomic hip center for achieving a sufficient contact with the host bone.

Bulk grafting with either femoral head autograft or allograft and cement has been reported to be filled in the location with deficient bone stock and furthermore to be helpful for rebuilding the native hip center[7-10] with a successful early follow-up. But long-term follow-up studies have proven a high incidence of aseptic loosening.[9,10]

Most clinical studies demonstrated that using a high hip center (HHC) could obtain good clinical results, especially in those patients with better acetabular bone stock superior to the anatomic hip center.[11-15] Obviously, the HHC could offer a chance to achieve better cup coverage with a cementless cup, which ensures initial stability, bony ingrowth, and long-term success in revision acetabular reconstruction.

However, the elevated heights of the rotation center and prosthesis survival rate vary from each study. Previous studies claimed that a 1% increase in hip load will occur for displacement 10 mm proximal of the rotation center,[16] proper superior migration of the rotation center will not

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increase hip load dramatically, since the most common reason for surgery failure with the HHC was insufficient coverage of the cup. Anatomical studies concerning the bone stock above the acetabulum are seldom reported. Antoniades and Pellegrini studied cross-sectional anatomy of the ilium from 16 cadaveric hips,[17] claimed that there are substantial anatomic limitations to high hip reconstructions 2 cm above the acetabular dome, however, there were many limitations, and there is also some concern whether the calculations made in people of Caucasian descent can be generalized to Chinese people given that Chinese people generally have a smaller physique than white people.

We therefore, determined the thickness and width of the human ilium by measuring every section in mimics, and we also calculated cup coverage related to every specie thickness and width by a mathematical equation.

Methods

Study subjects

A total of 120 normal iliums in 60 adult Chinese patients (34 men, 26 women) were chosen from those who received computer tomographic (CT) angiography for diagnosing vascular diseases in Digital Imaging and Communications in Medicine (DICOM) database for this study. The average age was 55.2 years (range, 30–66 years), the average height was 161.5 cm (range, 149–187 cm), and the average weight was 62.7 kg (range, 47–90 kg). Patients were included if they did not have severe osteoarthritis changes in hip and any deformities in the pelvis.

Computed tomography

The CT scans were performed previously with a Toshiba brand Aquilion CT scanner (120 kVp; 320 mA; 512*512 matrix; slice thickness, 0.5 mm) at the China-Japan Union Hospital of Jilin University. All patients were placed supine on the scanner with both knees taped to the scanner platform in an extended position with their patellar facing towards the ceiling. The scanning procedure was performed to acquire 0.5 mm CT slices from pelvis to the ankle joint. All the slices were saved as DICOM.

Landmarks location and measurement

The DICOM data were imported into Mimics 16.0 (Materialise, Leuven, Belgium) software. The rotational centers of the hips were obtained by drawing spheres to fit the femoral heads [Figure 1]. Every 5-mm increments section of the ilium according the body sagittal axis in coronal plane from the rotational center of the hip to the cephalic [Figure 1a] was marked, then measured the thickness (AB) and width (CD) of the pelvis in each slice [Figure 2]. The first slice was chosen at 25 mm above the rotation center, as the acetabular dome was located the place 25 mm above the rotation center for almost all the patients.

To calculate the acetabular cup coverage rate at different levels above the rotation center, an equation improved from Antoniades and Pellegrini[17] two-dimensional (2D) linear acetabular cup coverage equation was used to estimate the three-dimensional (3D) bony coverage rate of 40-, 50-, and 60-mm acetabular shells [Figure 3].

The cup coverage rate equals to: $1-\dfrac{\sqrt{R^2-r^2}}{R}$.

Results

The results of measured thickness and the width of the ilium are shown in details in Table 1. The width was larger than the thickness in each cross-section, with the maximum difference of at the point 25 mm above the rotation center, which close to the acetabular dome [Figure 2a]. At the acetabular dome, the average thickness and width of the ilium were 49.71 ± 4.88 mm and 38.92 ± 3.67 mm, respectively. Whereas at 1 cm above the dome (35 mm above the rotation center), the average thickness and width were decreased to 41.35 ± 5.13 mm and 31.13 ± 3.37 mm, and at 2 cm (45 mm above the rotation center) above the dome, the average thickness and width were decreased to 31.25 ± 4.04 mm) and 26.65 ± 3.43 mm. With the slices went up above the rotation center, the thicknesses and the width of the pelvis were decreased sharply. Considering the cups were placed at 45° inclination, the restricted boundaries of cup coverage were not in accordance to the values of AB but rather the values of CD, since the values of $\sqrt{2\text{AB}}$

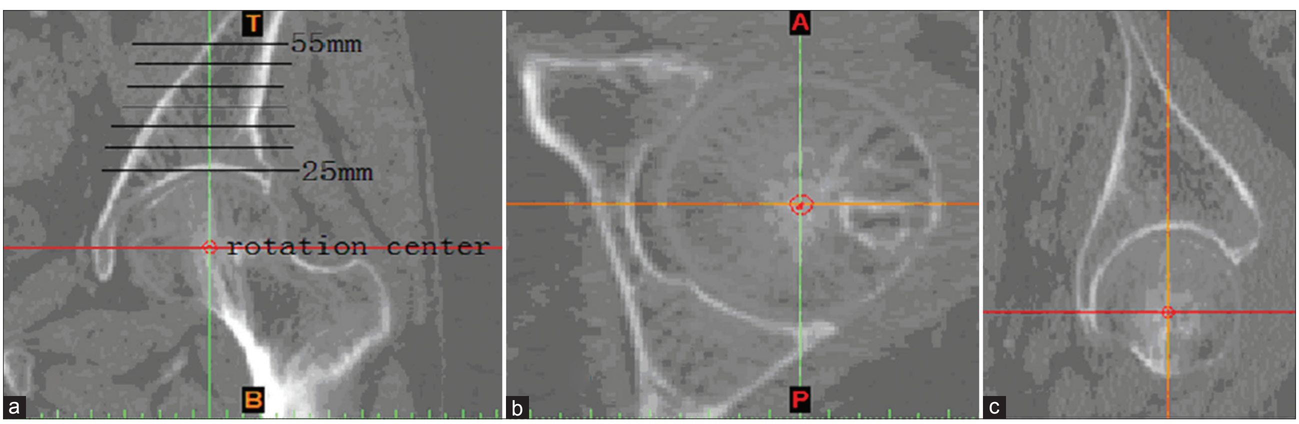

Figure 1: Demonstration of the rotation center in coronal, transverse, and sagittal plane. (a) Illustrated the locations of the slices applied in our study.

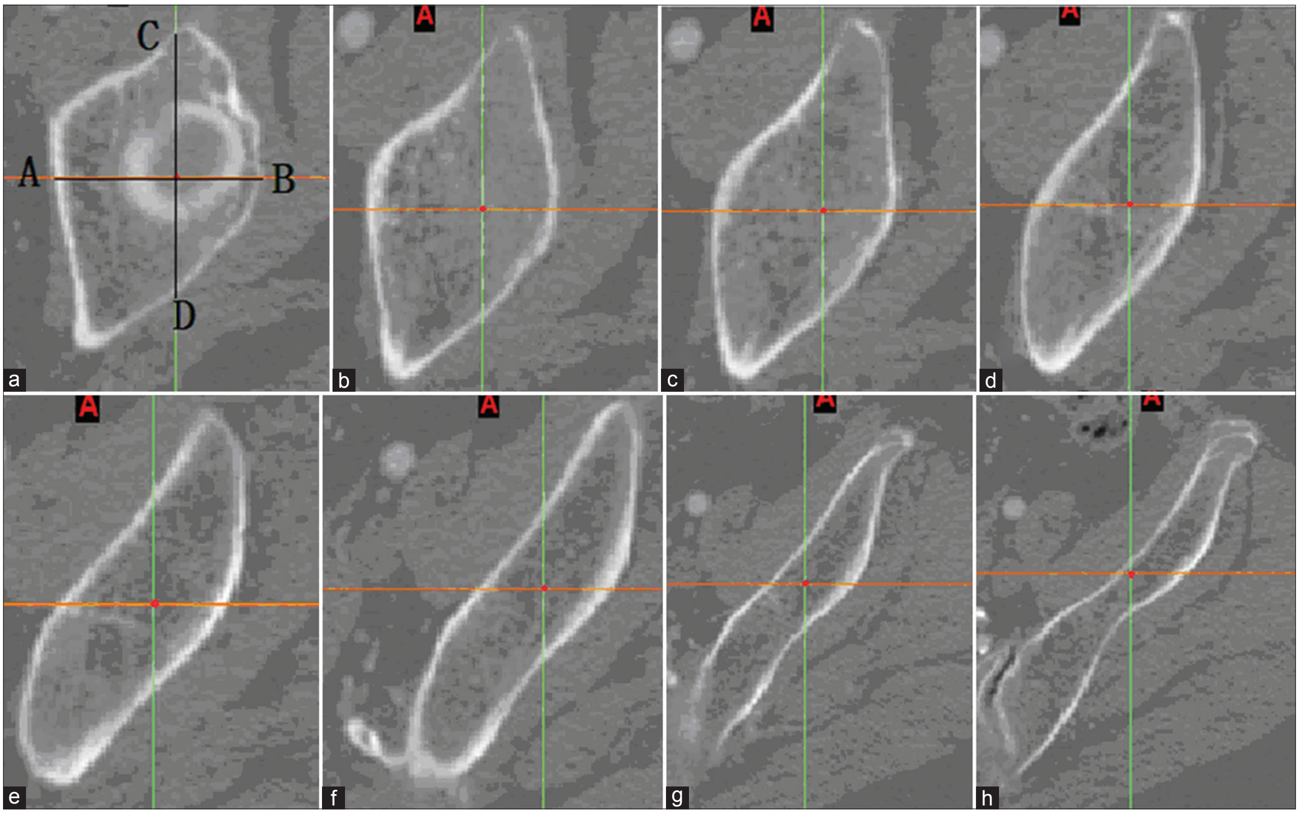

Figure 2: (a-h) Demonstrated the cross-sections from 25 to 60 mm above the rotation center respectively, and the measuring method was also shown on each slice. Figure 2a is cephalic of the ilium and Figure 2h is caudal of the ilium. Thickness = AB; Width = CD.

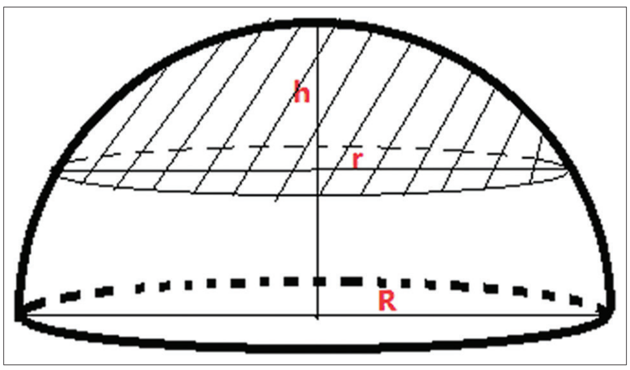

Figure 3: The covered part of the acetabular component. The shadowed part was covered with the host bone. R = The prosthesis radius; r = 1/2 of line AB or CD; h = The depth of the covered part of the cup.

were bigger than those of CD [Table 1]. The mathematical model [Figure 3] was applied to calculate acetabular cup coverage for 40-, 50-, and 60-mm hemispheric shells, and the average results were 100%, 89%, and 44% at the acetabular dome, 100%, 43.7%, and 27.5% at 1 cm above the dome, 37.5%, 21.9%, and 14.2% at 2 cm above the dome, and 14.9%, 9.0%, and 6.1% at 3 cm above the dome [Table 2].

Discussion

In the present study, we determined that the acetabular cup coverage rate varies across each section and individuals, within 1 cm above the acetabular dome being acceptable. Our 3D measurement method may have solved some measurement limitations of the cadaveric approach used previously. The ilium thickness and width reached its peak 25 mm above the rotation center, approximately at the acetabular dome, and decreased quickly to approximately, especially 2 cm above the doom. At that height above the dome, a 50-mm cup would have only 21.9% coverage by our equation calculation. According to our result, a 50-mm cup had only 43.7% coverage at 1 cm above doom. Therefore, it is necessary to apply screws to achieve initial cup stability.

HHC was applied to perform reconstruction of the acetabulum in those patients with peri-acetabular bone defect or osteolysis with good clinical results.[11-15] However, there were also studies claimed that the risk of loosening was greater if the hip center was raised 30 mm above the teardrop.[18,19] For now, none of the studies had reported the correlation between the loosening rate and the elevated height of the hip center. In addition, superior-only hip center relocation did not significantly affect the total joint force.[16] Although some surgeons claimed beneficial biomechanical effects of hip center medialization, our results do not recommend the empiric suggestion in HHC, the cup should be moved as medial as possible to improve acetabular component coverage,[1,11,16] because our data provided no anatomic basis to ensure that increased medialization of the cup resulted in better bony coverage, moreover, medialization would increase

Table 1: Summary of value of AB and CD every 5-mm increments section of the ilium from 25 to 55 mm above rotational center (mm)

Items	25 mm	30 mm	35 mm	40 mm	45 mm	50 mm	55 mm
CD	49.71 ± 4.88	45.98 ± 5.36	41.35 ± 5.13	35.69 ± 4.52	31.25 ± 4.04	25.89 ± 3.59	20.68 ± 3.9
AB	38.92 ± 3.67	34.33 ± 3.85	31.13 ± 3.37	28.8 ± 3.2	26.65 ± 3.43	24.19 ± 4.59	21.47 ± 4.69
$\sqrt{2AB}$	55.04	48.54	44.03	40.72	37.68	34.20	30.36

AB presents the iliac thickness and CD presents the iliac width.

Table 2: Coverage rates of the different diameter cups 40-, 50-, 60-mm at the level of 5-mm increments section of the ilium from 25 to 55 mm above rotational center (%)

Cups	25 mm	30 mm	35 mm	40 mm	45 mm	50 mm	55 mm
40 mm	100	100	100	54.8	37.5	23.8	14.4
50 mm	89.0	60.7	43.7	30.0	21.9	14.4	9.0
60 mm	44.0	35.8	27.5	19.6	14.2	9.8	6.1

the risk of breakthrough into the inner wall of the acetabulum and the difficult of rebuild the arm of gluteal muscle. Therefore, we conducted this measurement to evaluate the elevated height of HHC, attempting to afford anatomical basis.

Antoniades and Pellegrini[17] measured the thickness of the ilium using cadaveric ilium and calculated the linear coverage of the cup, suggested that there were substantial anatomic limitations to high hip reconstructions 2 cm above the acetabular dome. But, there were limitations in his study, including small sample size and the linear cup coverage rate estimated in 2D. Moreover, the Caucasians' data may not be suitable as a reference for Asians. We conducted this measurement by obtaining the data from 60 Chinese patients (120 ilium), and obtained the thickness of the ilium, which was smaller than Caucasians. To calculate the cup coverage in 3D, we also measured the width of ilium. However, the conclusion of our study recommended that the elevated height within 1 cm above the doom would obtain sufficient coverage for Asian.

There were also some limitations in our study. First, we did not consider the affection of bony stock in the sagittal plane, and the main reason was that the sagittal stock bone would affect cup coverage seldom as for 45° inclination cup placement. Second, the study speculated the cup survival rate was correlated with the initial cup coverage rate, with the lacking of supporting clinical random control trails. Third, the version of the cup will affect the cup coverage slightly, but in this study, we did not take into count. Finally, the soft tissue balance did not take into count, the following study we would analysis the mechanics and soft tissue balance of the hip joint after HHC technique by finite element analysis.[15,20]

We emphasized the Asian human ilium anatomy in a clinically relevant HHC technique during total hip arthroplasty. Furthermore, we estimated that place the hip rotation center within 1 cm of the intact acetabular dome would achieve perfect initial coverage and a prosthetic stability. Larger cup prosthesis may increase the loosening rate as for lower coverage rate of the cup. Moreover, in complicated acetabular reconstruction surgeries, CT scanning will be necessary in performing preoperative planning, since that will provide detailed iliac bony stock situation, quantify the level of the hip center elevated and the stress variation, furthermore achieve good prosthesis survival rate.

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