The anatomic structure of the normal hip joint depends on dynamic interaction between the proximal femur and acetabulum. Abnormal interaction due to variation in the orientation of either the acetabulum, proximal femur, or a combination of both can directly damage the hip. There are two types of hip diseases associated with morphological abnormalities of the acetabulum. Acetabular dysplasia caused by an anteverted shallow acetabulum is associated with deficiency of anterior, superior, or lateral coverage of the femoral head. Causes of pincer-type femoroacetabular impingement (FAI) include increased acetabular depth and acetabular retroversion, leading to anterior or lateral overcoverage of the femoral head. Normal references for acetabular parameters are needed because the diagnosis of these two diseases depends on quantitative parameters of the acetabulum. Normal references for acetabular parameters are also essential for total hip replacement arthroplasty. Malposition of the acetabular component in total hip arthroplasty can cause dislocation, wear, osteolysis, and limited range of motion. Although the safe range for the positioning of acetabular components has been suggested, there are wide interindividual variations in acetabular anatomy in normal population. Some acetabular parameters are significantly different among different populations.

**Background:** The normal references for acetabular parameters are important for the diagnosis of hip diseases and planning of total hip arthroplasty. There are wide interindividual differences in acetabular morphology in the normal population, and little is known about differences in acetabular morphology in the average South Korean population. The purpose of this study was to evaluate side and sex differences in acetabular morphology in the South Korean population.

**Methods:** The acetabular parameters, including anteversion angle, abduction angle, center-edge angle, acetabular width and depth, and acetabular-head index, were measured on three-dimensional computed tomography images in 197 healthy Korean adults. Differences in acetabular parameters according to side and sex were evaluated.

**Results:** The mean acetabular anteversion angle of men and women was $17.3^\circ \pm 5.2^\circ$ and $20.1^\circ \pm 3.5^\circ$, respectively. The mean acetabular width of men and women was $61.5 \pm 4.6$ cm and $56.5 \pm 4.0$ cm, respectively. There were significant sex differences in acetabular anteversion angle ($p = 0.001$) and acetabular width ($p = 0.036$) when adjusted for age, body height, and weight. The mean acetabular width of the right side and the left side was $60.2 \pm 5.2$ cm and $57.8 \pm 4.5$ cm, respectively. There were significant side differences in acetabular width ($p = 0.007$) when adjusted for age, body height, weight, and sex.

**Conclusions:** Differences and reference ranges of acetabular parameters are important for the diagnosis of acetabular deformity, such as femoroacetabular impingement and acetabular dysplasia. Moreover, these differences and reference ranges are useful for preoperative planning and safe positioning of acetabular components in total hip arthroplasty.

**Keywords:** Acetabular morphology, Sex, Three-dimensional computed tomography
people depending on sex and side.\textsuperscript{15,16} Therefore, sex and side differences in acetabular anatomy should be considered for diagnosing hip diseases and planning total hip arthroplasty. However, little is known about variations of acetabular anatomy in average South Korean adults. Thus, the purpose of this study was to evaluate side and sex differences in acetabular morphology in a normal South Korean population.

**METHODS**

This study was approved by the Institutional Review Board of Jeju National University Hospital (No. 2020-03-033). All methods were performed in accordance with the relevant guidelines and regulations (Declaration of Helsinki). Patient informed consent was waived by the Institutional Review Board due to the retrospective nature of the study. This study retrospectively analyzed acetabular parameters in 197 healthy South Korean adults (87 men and 110 women). Patients who visited the radiology department and underwent screening for other diseases were recruited from January 2009 to December 2013. The number of the study population (n = 197) satisfied the optimal sample size calculated using G-Power program (a free statistical program available at http://www.gpower.hhu.de/). None of them suffered from hip osteoarthritis, congenital or developmental hip morphology changes such as dislocation, subluxation, or dysplasia, previous surgery, or trauma to the hip. For male patients, their mean age, height, and weight were 60.4 ± 13.8 years, 166.5 ± 7.1 cm, and 65.2 ± 9.8 kg, respectively. For female patients, their mean age, height, and weight were 68.7 ± 12.5 years, 154.2 ± 6.0 cm, and 56.0 ± 9.3 kg, respectively.

Patients were placed in supine position with the knee joints fully extended and the patella facing forward for three-dimensional computed tomography (3D-CT) examination using a 64-layer CT scanner (Siemens Medical Solutions, Erlangen, Germany). Scanning parameters were as follows: 1.0 mm in layer thickness and 0.6 mm in reconstruction interval. Data were transmitted to a Siemens image post-processing work station to obtain 3D reconstruction images. The following parameters were measured using the 3D reconstruction images. Acetabular anteversion angle (AVA) was measured on axial CT images. AVA was defined as an angle formed by a line passing through the anteroposterior acetabular ridge and another line drawn perpendicular to a line connecting the posterior pelvic margins at the sciatic notch level (Fig. 1). Other acetabular parameters were measured on anteroposterior CT images. Acetabular width was measured as a distance between the most superolateral point and the lowermost point of the acetabulum. Acetabular depth was measured along the perpendicular line extending from the top of the acetabular roof to the bottom of the acetabulum. Center-edge angle was defined as an angle between a vertical line drawn through the femoral head center and another line passing from the femoral head center to the superolateral point of the acetabulum. Acetabular index was calculated with the following formula: depth / width × 100 (%) (Fig. 2). Acetabular abduction angle (ABA) was measured as an angle formed by a horizontal line passing through the bot-
tom of the acetabular tear drops and a line drawn from the teardrop to the lateral margin of the acetabulum. Acetabular head index was calculated using the following formula: width of the sourcil (I) / femoral head width (H) × 100 (%) (Fig. 3).

Interobserver and intraobserver reliability was assessed using the interclass correlation coefficient of the measurements, and an agreement of 0.75 was considered excellent. Differences in acetabular parameters according to side and sex were evaluated. Each acetabular measurement was assessed using descriptive statistical analysis. Side and sex differences for each acetabular parameter were assessed using the $t$-test. Analysis of covariance was used to compare differences in acetabular parameters between sexes and sides after adjusting for age, body height, and weight. Age and sex differences for each acetabular parameter were assessed using one way analysis of variance. A $p$-value ≤ 0.05 was considered statistically significant. Data were analyzed using IBM SPSS ver. 19.1 (IBM Corp., Armonk, NY, USA).

RESULTS

Each parameter showed good to excellent interobserver and intraobserver agreement. Average values of all acetabular parameters in both sexes are displayed in Table 1. Compared to men, women had significantly greater AVA ($p = 0.001$) and ABA ($p = 0.012$) and significantly smaller center-edge angle ($p = 0.026$), acetabular width ($p < 0.001$), and depth ($p < 0.001$). Sex differences in AVA ($p = 0.001$) and acetabular width ($p = 0.036$) were significant after adjusting for age, body height, and weight. Average values of all acetabular parameters of both sides are displayed in Table 2. There were significant side differences in acetabular width ($p = 0.002$), which were also significant after adjusting for age, body height, and weight ($p = 0.007$). Average values of all acetabular parameters by age and sex are presented in Table 3. There was no significant difference in acetabular parameters according to age.
DISCUSSION

The normal range of acetabular parameters is important for distinguishing acetabular deformity and planning total hip arthroplasty. However, there are wide interindividual variations of acetabular parameters in people of different sex, as well as between right and left hips. However, there is no consensus on normal ranges of acetabular parameters. There are previous studies that evaluated differences of acetabular parameters by sex and side based on plain radiography, which may not have been accurate enough due to its limitations in measurement based on positions. In the current study, 3D-CT reconstruction images were used to evaluate differences of acetabular parameters between men and women and between right and left sides. As measurements could be performed in any plane and any direction using 3D reconstruction images, 3D-CT allows more accurate measurements than plain radiography.

Previous data on sex-related difference in acetabular parameters are inconsistent. Many studies showed that AVA was significantly larger in women than in men as in our study. Acetabular parameters in normal male populations showed more retroversion of the acetabulum than in female counterparts, indicating men are anatomically more prone to pincer-type FAI. However, many clinical studies have shown that the incidence of pincer-type impingement was more frequent in women than men. Cobb et al. reported that there was no significant difference in AVA between pincer-type FAI patients and normal acetabular patients, suggesting there are other contributing factors in the higher prevalence of pincer-type FAI in women other than anatomical positions of the acetabulum. Potential causal anatomical factors such as coxa profunda, acetabular protrusions, and femoral retroversion in pincer-type FAI should be evaluated in addition to sex differences in further research. Some studies showed that acetabular width was significantly larger in men than women. Our results showed that acetabular width was significantly different between sexes after adjusting for body height and weight.

Previous comparative studies on acetabular parameters of both acetabulums have demonstrated inconsistent results. Buller et al. and Tallroth and Lepisto failed to find significant differences in any acetabular parameters between left and right hips. However, Vandenbussche et al. reported differences in acetabular parameters between right and left hips. In addition, our results indicated significant differences in acetabular width between right

| Parameter                   | Anteversion (°) | Abduction (°) | Center-edge (°) | Width (cm) | Depth (cm) | Acetabular head index (%) |
|-----------------------------|----------------|--------------|----------------|------------|------------|--------------------------|
| Male                        | 18.3 ± 8.5     | 42.1 ± 4.2   | 37.0 ± 4.6     | 60.5 ± 4.0 | 38.7 ± 8.4 | 83.9 ± 5.4               |
| Female                      | 18.8 ± 3.6     | 45.4 ± 2.9   | 37.0 ± 2.4     | 55.1 ± 2.2 | 38.7 ± 8.4 | 83.9 ± 5.4               |

Table 3. Differences in Acetabular Parameters by Age and Sex

Values are presented as mean ± standard deviation.
and left acetabulums after adjusting for body height and weight. Side difference in acetabular width was also statistically significant after adjusting for body height, weight, and sex.

Inconsistent results on sex- and side-related differences in acetabular parameters in previous studies might have originated from geographic and racial differences in acetabular parameters. We summarized the acetabular parameters according to countries and confirmed that there was some difference (Table 4). The cause of these differences can be genetic or cultural (the way babies are carried may affect hip development). Moreover, a previous study reported that side differences of acetabular or proximal femoral parameters were associated with the dominant leg because the dominant leg may bear greater loading force than the non-dominant leg. Although the cause of sex- and side-related differences in acetabular parameters needs to be further studied, acetabular width is an important factor in restoring normal hip mechanics and the awareness of sex and side differences in acetabular width could be helpful for planning total hip arthroplasty.

The safe range for the position of the acetabular component is important during total hip arthroplasty. An ABA of 40° ± 10° and an AVA of 15° ± 10° have been considered as safe zones. However, in the current study, we found that there were sex and side differences in AVA in a normal Koran population. Therefore, the optimal acetabular position in total hip arthroplasty differs between individuals. The exact placement of acetabular components within the safe zone may not be good for every patient. Kennedy et al. have suggested the use of native acetabular position as a guide for acetabular component placement during total hip arthroplasty. It is also important to evaluate the width and depth of the acetabulum in preoperative planning for total hip arthroplasty. The size of an acetabular implant is also important in total hip arthroplasty. The geographic discrepancy between the implant and acetabular anatomy often results in partial prosthetic overlap of the acetabular rim. This discrepancy leads to iliopsoas impingement caused by the chronic friction of the iliopsoas tendon and rim of the implant. In the current study, we found that there were sex and side differences of acetabular width in a normal Koran population. Therefore, sex and side-related differences in acetabular parameters are critical for accurate position and anatomical alignment of total hip arthroplasty components. Preoperatively determining acetabular parameters with CT scanning is important for optimum acetabular component placement in total hip arthroplasty.

This study has some limitations. First, all acetabular
parameters were measured by a single investigator. Second, because of the retrospective nature of this study, the position of patients during CT scan was not fully controlled. In addition, the study sample size (197 participants) was relatively small to draw a definite conclusion. Thus, a large multicenter study is needed to investigate the reliable acetabular parameters in South Korean population. Lastly, side differences in acetabular parameters between dominant and non-dominant legs were not evaluated in the current study. This requires future investigations.

In summary, this study confirmed that there were morphological differences in the acetabulum based on sex and side. A set of reference ranges for normal acetabular parameters were provided for South Korean population. These differences and reference ranges for acetabular parameters are important for the diagnosis of acetabular deformity, such as FAI or acetabular dysplasia, and useful for preoperative planning and safe positioning of acetabular components in total hip arthroplasty. A large multicentric study is needed in the future to confirm specific reference ranges in South Korean population for total hip arthroplasty.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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