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Original Article

Sex differences in reference values of hip acetabular measurements using computed tomography in Japanese adults and the effect of aging on the measurement parameters

Yuya Yamatani [a, *], Mitsuru Munemoto [b], Eiji Ando [c], Hideki Shigematsu [c], Kenji Kawate [d], Yasuhito Tanaka [c]

[a] Division of Central Radiology, Nara Medical University Hospital, Nara, Japan
[b] Department of Orthopaedic Surgery, Higashiosaka City Medical Center, Osaka, Japan
[c] Department of Orthopaedic Surgery, Nara Medical University, Nara, Japan
[d] Department of Orthopaedic Surgery, Nara Prefectural General Rehabilitation Center, Nara, Japan

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A B S T R A C T

Background: It is very important to understand the acetabular morphology of the normal hip joint to assist in diagnosis and surgical planning of hip disorders. The purpose of the present study was to obtain gender-based reference values for the acetabular measurements of a normal hip using computed tomography data and investigate the effect of aging on the measurement values.
Methods: We measured acetabular parameters (center-edge angle, Sharp angle, vertical center anterior angle, acetabular anteversion) on computed tomography corrected for changing the obliquity, rotation, and tilt of the pelvis. We performed measurements in 245 patients (490 joints; 120 men [240 joints] and 125 women [250 joints]). The mean age was 64.7 ± 14.3 (31–88) years for men and 63.2 ± 15.2 (30–88) years for women.
Results: In men and women, the mean center-edge angle was 31.8° ± 6.4° and 30.6° ± 6.5°, the mean Sharp angle was 38.6° ± 3.2° and 40.6° ± 3.8°, the mean vertical center anterior angle was 44.3° ± 7.9° and 40.0° ± 8.5°, and the mean acetabular anteversion angle was 14.3° ± 5.2° and 18.8° ± 5.4°, respectively. All differences were statistically significant. The center-edge angle increased with age in women; however, such an effect was not observed in men. The other measurements showed a similar trend, such as larger vertical center anterior angle and smaller Sharp and acetabular anteversion angles, with aging in both men and women.
Conclusions: We used computed tomography data to quantitatively assess the coverage and shape of the acetabulum in adult Japanese subjects and obtain the estimated reference ranges by gender. The results also proved that the measurements changed with aging in both sexes. These facts must be taken into account during the diagnosis of hip disease and planning of surgery.

1. Introduction

The morphology of the acetabulum in the pelvis and the degree of anterior and lateral coverage have been reported to be involved in the development of osteoarthritis and femoroacetabular impingement [1–4]. So far, there are reports of morphometric measurements using mainly radiograph [5–7] and plain computed tomography (CT) [8]. However, in the clinical setting, we consider that radiographic imaging is affected by certain conditions (pelvic tilt, body position, positioning at the time of performing imaging), reproducibility is low [9–11], and there are problems with regard to accuracy.

On the other hand, it has been reported that CT can measure the morphology of the acetabulum from a direction that cannot be measured by radiographic images and can perform more accurate measurements [12–14]. So far, there have been reports on the features of the acetabular morphology in cases with osteoarthritis and femoroacetabular impingement [14–17]. We consider that

* Corresponding author. Division of Central Radiology, Nara Medical University Hospital, 840 Shijo-Cho, Kashihara, Nara, Japan. Fax: +81 744 23 8907.
E-mail address: y-yama@naramed-u.ac.jp (Y. Yamatani).

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understanding the morphology of the acetabulum that causes these conditions is very important for treatment. Moreover, we also consider that it is very important to understand how the acetabular morphology differ in disease and normal conditions in order to anticipate the future development of osteoarthritis and femoroacetabular impingement. To date, several studies based on CT of the normal hip have been reported [18,19]. However, in those reports, the number of cases used for measurements was small. Moreover, it has only been shown that aging has an effect, but what changes occur with aging are not studied. The purpose of this study was to obtain a reference value for the acetabulum of a normal hip using CT data and to investigate the effect of aging on the measurement values.

2. Materials and methods

2.1. Subjects

The present study was approved by the Institutional Review Board and implemented in accordance with the principles of research ethics at the institution. All procedures performed in studies involving human participants were in accordance with the ethical standards of our institutional and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent for undergoing the CT procedures was obtained from each subject. The requirement of informed consent for participation in the study was waived because of the retrospective nature of the study.

The measurement modality in the present study was pelvic imaging; data obtained from abdominal and pelvic CT images taken at our hospital between September 2013 and October 2013 in departments other than the orthopedic surgery department were used. The data were classified by sex and further stratified by age group (less than 50 years, 50–59 years, 60–69 years, 70–79 years, and 80–89 years) and then randomly selected to collect 50 hips in each group. In addition, the exclusion criteria were as follows: (1) history of osteoarthritis (Kellgren and Lawrence grade 2 or higher), (2) history of pelvic bone surgery, (3) history of pelvic bone and femur fractures, (4) presence of a lesion such as metastatic bone tumors or cystic region, and (5) lack of a hip joint in the data range.

2.2. CT measurements and evaluation

CT analysis of the hip was undertaken using a 2 × 128-MDCT scanner (SOMATOM Definition Flash, Siemens Healthcare, Munich, Germany) and a 64-MDCT scanner (SOMATOM Definition AS, Siemens Healthcare Munich, Germany). The patients were placed in a supine position with their legs fully extended and their feet stabilized in a neutral position. The pelvis was scanned from the fourth lumbar vertebra to the lesser trochanter, with 0.6 mm collimation and 1 mm image reconstructions. The field of view was 350–450 mm. After downloading the data from these scans in Digital Imaging and Communications in Medicine format (DICOM; National Electrical Manufacturers Association, Rosslyn, Virginia) onto a personal computer, we performed multiple plane reconstructive imaging using image processing and analysis software (Zed Hip; LEXI, Tokyo, Japan).

For measurements, multiplanar reconstruction (MPR) was created using image analysis software (Zed Hip) and the parts thought to be osteophytes were excluded from the measurements. Moreover, in order to correct pelvic tilt, the anterior pelvic plane (APP) [20], which is a plane including the anterior superior iliac supine planes on both sides and the pubic tubercle, was set in a vertical state, and the bilateral femoral head centers were set to be in the same line in order to correct the rotation of the pelvis. Regarding the measurement method, the sphere most approximate to the femoral head was set and its center was taken as the center of the femoral head. In addition, all measurements were performed using a cross section passing through the center of the femoral head. The following measurements were conducted. The center-edge (CE) angle [7] for lateral coverage, the vertical center anterior (VCA) angle [5] for anterior coverage and the Sharp angle [6], and the acetabular anteversion (AcetAV) [8] for acetabular shape. The CE angle was defined as the angle between the perpendicular line connecting the centers of the bilateral femoral heads and the line connecting the femoral head center and the acetabular lateral margin. The Sharp angle was defined as the angle between the line connecting the acetabular lateral margin and the teardrop, and the line connecting the bilateral teardrops. The CE and Sharp angles were measured on the coronal plane passing through the center of the bilateral femoral heads (Fig. 1a). The measurement method for acetabular anteversion uses a transverse image passing through the center of the bilateral femoral heads and the angle formed by the line connecting the anterior margin and posterior margin of the acetabular crown and the perpendicular line connecting the bilateral femoral head centers (Fig. 1b). The VCA angle was measured on the plane (solid line in Fig. 1c) passing through the femoral head center. The measurement plane is a reconstructed oblique plane, with the sagittal plane perpendicular to the APP tilted at 25°on the lateral side (Fig. 1c). The VCA angle was defined as the angle between the vertical line passing through the femoral head center and the line connecting the acetabular anterior margin and the femoral head center (Fig. 1d).

All measurements using CT images were performed by one observer (Y.Y.) and were repeated in a blinded manner over two sessions, which were at least one month apart. Two observers (Y.Y. and E.A.) independently performed the CT measurements on 80 randomly selected hips. The intraobserver and interobserver reliabilities were evaluated with the use of the intraclass correlation coefficient (ICC).

2.3. Statistical analysis

Statistical analyses were performed using the JMP 12.0.3 (SAS Institute Inc., Cary, NC, USA) statistical software. Descriptive data were reported as mean ± standard deviation (SD) where appropriate. The Shapiro–Wilk test was used to examine the normality of the measured variables and the Levene test was used to assess the equality of variances in different groups. Student's or Welch's *t*-test were used to compare the data between men and women. The reference ranges were calculated as mean ± 2 standard deviations (SDs) for variables with a normal distribution and the 2.5th–97.5th quintile for variables with a non-normal distribution. To compare the mean values for each age group, a Kruskal–Wallis test was performed and if a significant difference was detected, a Steel-Dwass was performed. A p-value <0.05 was considered statistically significant.

3. Results

3.1. Patients

Men and women were randomly selected to ensure 50 hip joints per age group, although only 40 hip joints were present in the under 50s group of men. Nine patients with osteoarthritis (Kellgren and Lawrence grade 2 or higher), one with a history of pelvic bone

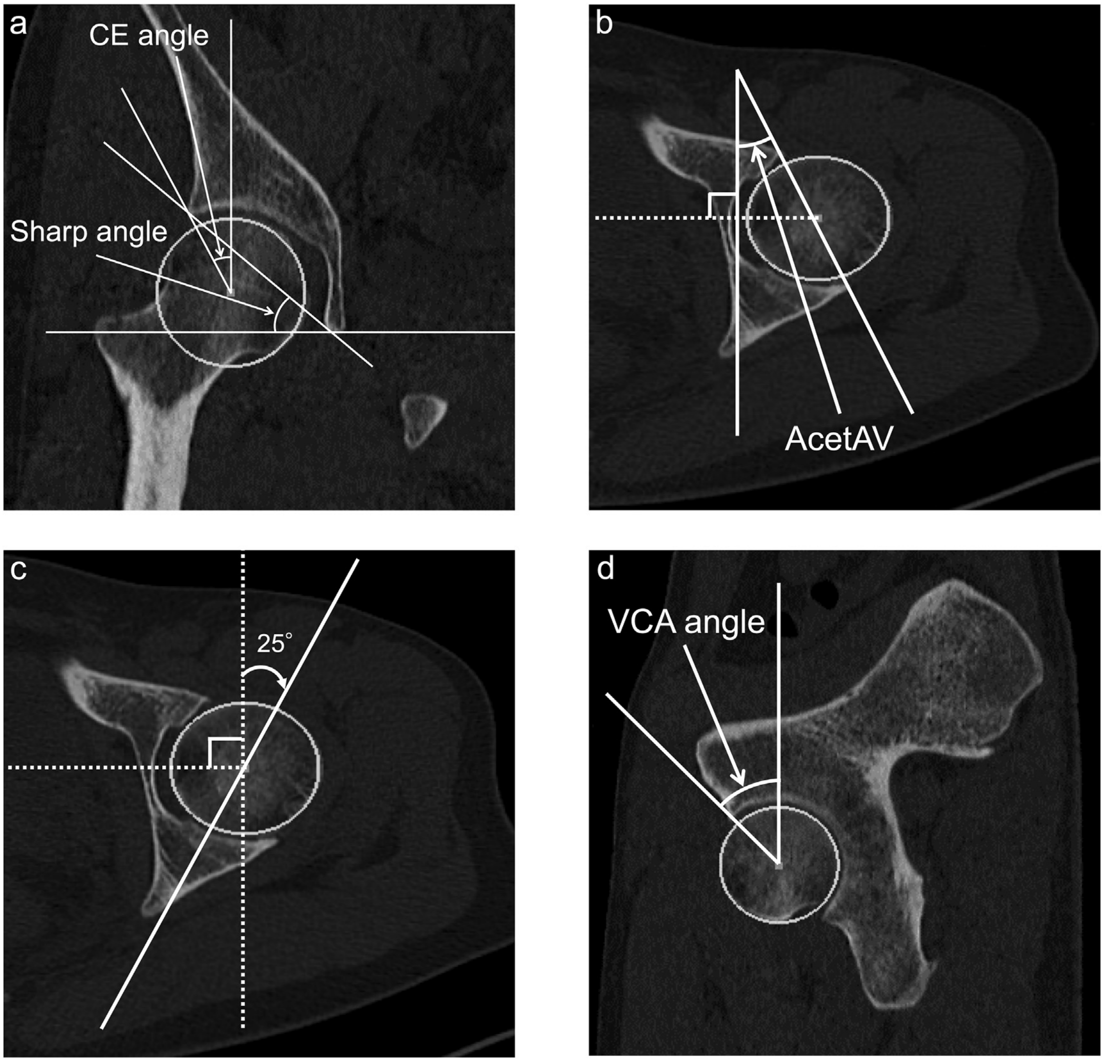

Fig. 1. Measurement of acetabular coverage and shape. (a) CE angle and Sharp angle. (b) AcetAV. (c) Plane to measure VCA angle. (d)VCA angle, CE, center-edge; AcetAV, acetabular anteversion; VCA, vertical center anterior.

surgery, three with a history of fracture, seven with the presence of a lesion such as metastatic bone tumors or cystic region, and seven with an insufficient imaging range were excluded from the study.

The final number of patients was 245 (490 joints); of these, 120 were men (240 joints) and 125 were women (250 joints). The mean age was 64.7 ± 14.3 years (31–88 years) for men and 63.2 ± 15.2 years (30–88 years) for women. Table 1 shows the details of each age group.

3.2. Sex differences in measurement items

In men, a normal distribution was observed for all measurement items except the CE angle, while in women, a normal distribution of the CE angle and sharp angle was observed based on the Shapiro–Wilk test (significance level of $p < 0.05$). The mean CE angle was 31.8° ± 6.4° in men and 30.6° ± 6.5° in women, with a significant difference between men and women ($p = 0.032$). The

Table 1
Age and sex distributions for the subjects.

		Age group					
		<50 years	50s	60s	70s	80s	Total
Men	N (joints)	40	50	50	50	50	240
	Age (years)[a]	42.6 ± 5.2	54.3 ± 3.1	64.7 ± 3.3	74.4 ± 3.4	82.9 ± 2.3	64.7 ± 14.3
	range	31–49	50–59	60–69	70–79	80–88	31–88
Women	N (joints)	50	50	50	50	50	250
	Age (years)[a]	40.4 ± 6.3	55.0 ± 3.1	63.9 ± 2.7	74.4 ± 2.6	82.6 ± 2.4	63.2 ± 15.2
	range	30–49	50–59	60–68	70–79	80–88	30–88
	p-value[b]	0.26	0.46	0.33	0.98	0.32	0.52

[a] Values are expressed as mean ± standard deviation.
[b] Statistical analysis was performed using the nonparametric Mann–Whitney test.

mean Sharp angle was significantly smaller (38.6° ± 3.2°) in men than in women ($p < 0.001$), while the mean VCA angle was significantly larger in men (44.3° ± 7.9°) than in women ($p < 0.001$). The mean AcetAV values were 14.3° ± 5.2° and 18.8° ± 5.4° for men and women, respectively, with a significant difference ($p < 0.001$). No negative values indicating posterior tilting of the acetabulum were noted for any patient. Table 2 shows the results of CT measurement items and their respective reference ranges.

3.3. The effect of aging on measurements

Among men, there was no significant difference in the CE angle between the age groups (Fig. 2a). The VCA angle in the 80s group (47.1° ± 8.2°) was significantly higher than that in 50s group (42.6° ± 8.1°) ($p = 0.035$; Fig. 3a). The Sharp angle was lower in the 80s group (37.3° ± 3.1°) than in the under 50s group (39.3° ± 2.9°) and the 60s group (39.0° ± 2.8°) ($p = 0.014$ and $p = 0.038$, respectively; Fig. 4a). The AcetAV was lower in the 80s group (11.8° ± 4.8°) than in the under 50s group (16.0° ± 5.5°), the 50s group (15.3° ± 4.9°), and the 60s group (15.5° ± 3.8°) ($p = 0.004$, 0.011 and $p < 0.001$, respectively; Fig. 5a). The Sharp angle and AcetAV angle decreased with age.

Among women, the CE angle was higher in the 80s group (34.3° ± 6.2°) than in the under 50s (27.0° ± 5.7°), 50s (28.4° ± 5.5°), and 60s (30.6° ± 6.8°) groups ($p < 0.001$, $p < 0.001$ and $p = 0.047$, respectively); the CE angle was grater in 70s group (32.5° ± 5.2°) compared to the under 50s and 50s groups ($p < 0.001$ and $p = 0.002$, respectively; Fig. 2b). The VCA angles were higher in the 80s (44.9° ± 9.0°) and 70s (42.1° ± 7.0°) groups than in the under 50s (36.1° ± 7.5°), 50s (37.9° ± 6.8°), and 60s (38.7° ± 8.8°) groups (80s; all $p < 0.001$, 70s; $p < 0.001$, $p = 0.035$ and $p = 0.027$, respectively; Fig. 3b). The Sharp angle was lower in the 80s group (39.0° ± 2.8°) than in the under 50s (42.3° ± 3.7°) and 50s (42.1° ± 3.9°) groups (both $p < 0.001$); the Sharp angle was lower in70s group (38.8° ± 3.5°) than in the under 50s and 50s groups (both $p < 0.001$; Fig. 4b). The AcetAV was lower in the under 50s (20.9° ± 4.4°) group than in the 70s (18.0° ± 5.8°) and 80s (17.2° ± 5.2°) groups ($p = 0.047$ and $p = 0.002$, respectively; Fig. 5b).

3.4. Reliability of measurements

Regarding the reliability of all measurements, the ICCs for intra-rater errors were 0.89–0.96 and those for inter-rater errors were 0.79–0.92. Thus, the reliability was extremely high.

4. Discussion

Understanding the detailed normal acetabular morphology is important for diagnosis and surgical planning. In the present study, we performed measurements on a total of 245 Japanese patients (490 hips) using CT images taken for reasons unrelated to hip joint disease. To the best of our knowledge, there has been no report with such a high number of cases.

In a previous study [21], using anterior radiographic images of the pelvis, the CE angle was shown to be 32.6° ± 6.9° in men and 32.1° ± 6.0° in women. Another study [22] revealed that both men and women had a reported the mean CE angle of 31°. No sex differences were reported in either of these studies. However, Inoue et al. [23] reported that the mean CE angle using urographic radiographs was 35.1° for men and 32.8° for women, with significantly smaller values for women ($p < 0.001$). In addition, in another study, where CT was performed in the same way as ours, there was no sex difference; however, it was not possible to compare results because of the inclusion of minors in that study [19]. According to our measurement results, the mean CE angle was 31.8° ± 6.4° and 30.6° ± 6.5° for men and women, respectively. The mean CE angles were equivalent to or smaller than those in previous reports, but the value for men was significantly greater than that for women ($p = 0.032$). Among the previous reports, some reported sex differences and some did not; however, the results of the present study revealed that when measurements are accurately performed, after correcting for pelvic incline and pelvic bone rotation, the CE angle is larger in men. Moreover, regarding the measurement of the Sharp angle to indicate the acetabular morphology, Nakamura et al. [21] examined Japanese patients and found that the mean value was 37.3° ± 3.7° for men and 38.6° ± 3.4° for women, and the criterion for acetabular dysplasia was set at 45° or more. The mean Sharp angle in the present study was 38.6° ± 3.2° for men and 40.6° ± 3.8° for women; these were slightly larger than those in previous reports and showed sex-based differences ($p < 0.001$). However, in the present study, the range of references was up to 45° and 49° for men and women, respectively. Therefore, it is necessary to have a separate criterion for assessing acetabular dysplasia using CT for each sex.

The VCA angle was used as an indicator of the anterior coverage rate of the acetabular angle, and the mean VCA angle obtained in the present study was 44.3° ± 7.9° for men and 39.9° ± 8.5° for women, being significantly smaller in women ($p < 0.001$). In addition, acetabular dysplasia is the main cause of osteoarthritis in Japan, with a higher prevalence in women. [1,23]. Such an

Table 2
Normal reference values for the acetabulum according to CT measurements.

Measurement item	Mean	SD	Median	Percentiles		Reference range	p-value
				2.5th	97.5th		
CE angle							
Men	31.8	6.4	31.5	20.3	46.5	20.3–46.5[b]	0.032
Women	30.6	6.5	30.3	17.7	43.5	17.6–43.6[a]	
Sharp angle							
Men	38.6	3.2	38.9	31.7	44.2	32.0–45.2[a]	<0.001
Women	40.6	3.8	40.7	32.5	49.0	33.0–48.2[a]	
VCA angle							
Men	44.3	7.9	43.9	28.0	62.9	28.5–60.1[a]	<0.001
Women	40.0	8.5	40.0	25.7	59.2	25.7–59.2[b]	
AcetAV							
Men	14.3	5.2	14.6	3.0	25.2	3.9–24.7[a]	<0.001
Women	18.8	5.4	19.4	5.7	28.5	5.7–28.5[b]	

CT, computed tomography; CE, center-edge; VCA, vertical center anterior.
AcetAV, acetabular anteversion; SD, standard deviation.
[a] The reference range is mean±2SD for normally distributed data.
[b] 2.5th–97.5th quintile for non-normally distributed data.

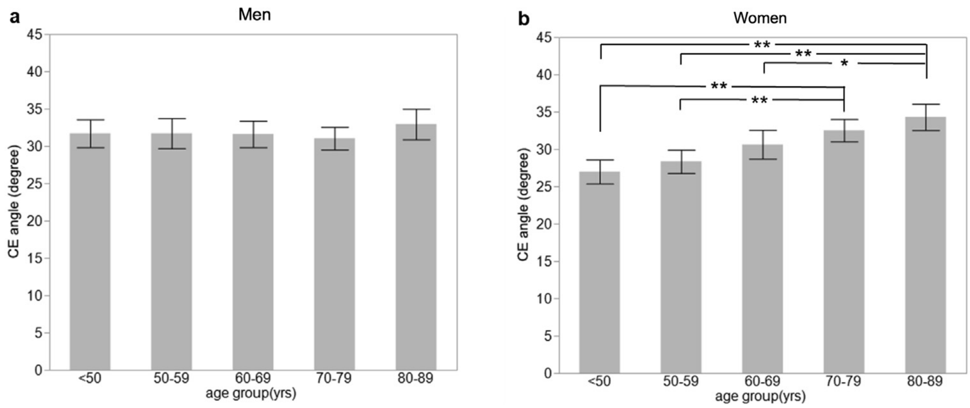

Fig. 2. Comparison of the CE angle by age group. (a) men (b) women, Error bars represent 95% confidence intervals of the mean. Steel-Dwass multiple comparison (**: P < 0.01, *: P < 0.05), CE, center-edge.

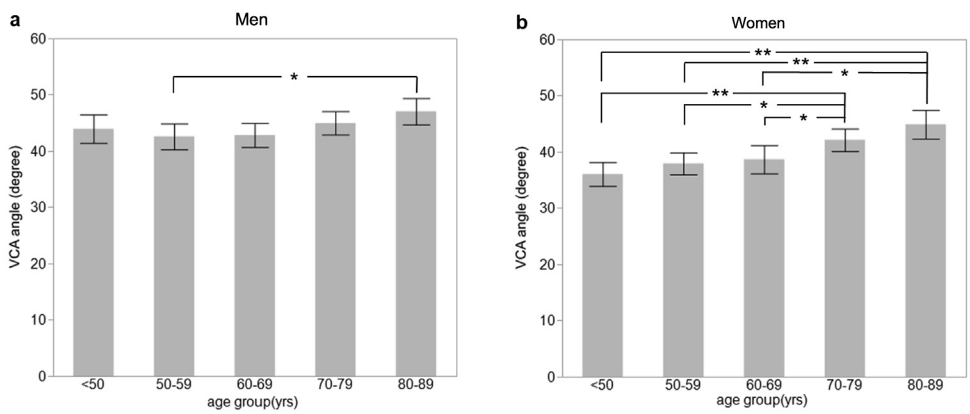

Fig. 3. Comparison of the VCA angle by age group. (a) men (b) women, Error bars represent 95% confidence intervals of the mean. Steel-Dwass multiple comparison (**: P < 0.01, *: P < 0.05) VCA, vertical center anterior.

observation is in line with the results of the CE and VCA angle measurements in our study that showed women had a lower anterior and lateral coverage than men, which may affect the onset of osteoarthritis.

Regarding the AcetAV angle, to date, no clear difference has been reported between normal hip joints and hips with acetabular dysplasia. The acetabulum in acetabular dysplasia is lower in both anterior and posterior directions and the coverage of the femoral head is smaller compared to the normal hip joint. The AcetAV angle was not necessarily large in the normal group, and there are many studies that showed the mean value of the AcetAV angle is approximately 20°; the angle changes significantly depending on which part of the acetabulum is hypoplastic [8,14,24,25]. In the present study, the mean value of the AcetAV was 14.3° ± 5.2° for men and 18.8° ± 5.4° for women, suggesting that anteversion is higher in women. This finding indicates that women have less anterior coverage than men with respect to acetabular coverage, as well as a smaller VCA angle. In radiographic studies, the shape of

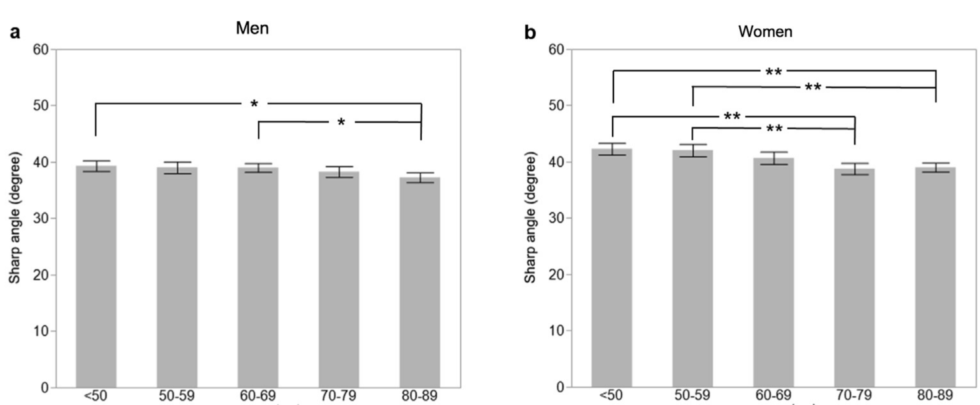

Fig. 4. Comparison of the Sharp angle by age group. (a) men (b) women, Error bars represent 95% confidence intervals of the mean. Steel-Dwass multiple comparison (**: P < 0.01, *: P < 0.05).

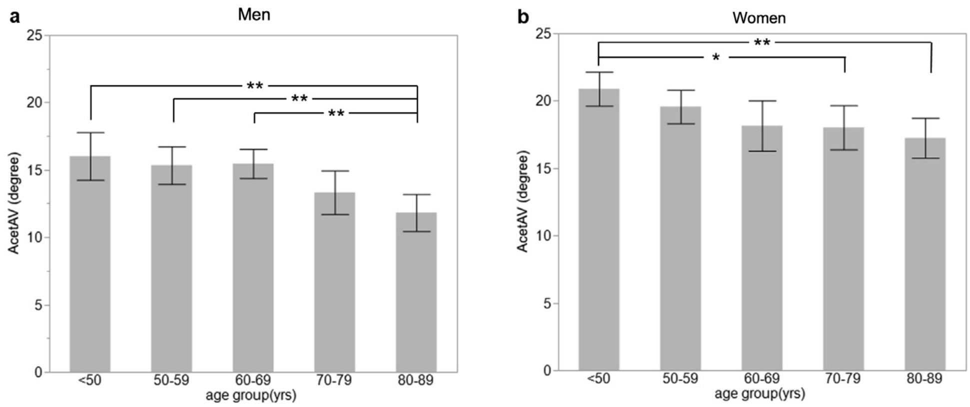

Fig. 5. Comparison of the AcetAV angle by age group. (a) men (b) women Error bars represent 95% confidence intervals of the mean. Steel-Dwass multiple comparison (**: $P < 0.01$, *: $P < 0.05$) AcetAV, acetabular anteversion.

the hip joint has been reported to vary by race [26]. Similar to the present study, in past reports using CT in a Chinese population [27] and a Finnish population [28], no sex differences were noted in the CE angle, and the angles were larger than those in the Japanese population in the current study. The AcetAV angle was larger in the American [29] and Finnish populations than in the Japanese population, for both men and women. In the Chinese population, only Chinese men had larger angles than Japanese men, but there was almost equal for women in these populations.

Age-related effects of acetabular measurements were observed in both men and women. To date, there have been few reports on the effects of aging on measurements value in Japan. Miyasaka et al. [19] reported that the AcetAV angle in men was larger the elderly population than the younger population and in women was unaffected for aging. Moreover, they reported a decrease in the Sharp angle and an increase in the CE angle in both sexes due to aging. However, in our study, only the CE angle was unaffected by aging in men, and other measurements changed at the age of 80 years or more. In addition, in women, the CE and VCA angles changed with age, while the Sharp and AcetAV angles began to be affected after 70 years of age. The study by Miyasaka et al. [19] included a smaller number of cases than did the present study, and it also included a number of underaged cases. They also noted that the standard division is very large in the elderly population for the AcetAV angle, which is a problem. Furthermore, age-related changes in pelvic morphology in healthy children have been reported [30] in the past, so comparisons are difficult to make.

In women, it is well known that during pregnancy, ligaments can loosen and the shape of the pelvic bone can deform [31]. In addition, we considered the possibility that women have weaker muscles than men and that the effects of aging are more pronounced in women than in men because of the stretching of ligaments during pregnancy and childbirth.

This study has some limitations. First, it is a cross-sectional study; however, CT scans cannot be performed multiple times to measure the shape of the acetabulum because of exposure to high radiation dose. In addition, longitudinal studies are very time consuming. Second, due to cross sectional study design, we might have excluded the cases wherein osteoarthritis occurred with age; those cases might have small CE and VCA angles as well as large Sharp angle. Such exclusions of age-related osteoarthritis cases might affect the measurements of our study. Third, according to the medical records, the physical findings of all subjects were not noted. For example, there were no hip joint symptoms noted, but it is unknown whether the cases were actually asymptomatic, because CT images of patients who underwent CT examination for other reasons were included. Fourth, this study did not include subjects in their 20s, and very few younger patients were enrolled. Fifth, the measurement of the VCA angle is conventionally performed using radiographic images taken during standing load; thus, strictly speaking, the CT images measured in the present study differed as they were taken with the subjects in the supine position. However, because we consistently measured the anterior coverage rate on a plane passing through the center of the femoral head under uniform conditions, we believe that this is not a problem. Finally, although we have found statistically significant differences between sexes and ages for each measurement, some of those differences were slight differences in angle and might be attributable to potential errors in measurements. Such errors in measurement when using pelvic CT measurement needs to be explored further in future studies.

In conclusion, we used CT data to measure the pelvic tilt and rotation under uniform conditions, and quantitatively assessed the coverage and shape of the acetabulum in adult Japanese subject to obtain the estimated reference ranges by gender. Our results proved that the measurement values changed with aging in both sexes. Thus, the results of this study demonstrate that acetabular morphology differs in adult Japanese men and women. These facts must be taken into account during the diagnosis of hip disease and planning of surgery.

Study design

Retrospective and cross - sectional study.

Declaration of competing interest

None.

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