Original Article

HEALTH SCIENCES
MEDICINE

DOI: 10.32322/jhsm.910775
J Health Sci Med 2021; 4(3): 358-365

Volume-based dysplasia severity index with the spheric cup method in the evaluation of adult and adolescent acetabular dysplasia

Mehmet Burtaç Eren

Tokat Gaziosmanpaşa University Faculty of Medicine, Department of Orthopaedics and Traumatology, Tokat, Turkey

Cite this article as: Eren MB. Volume-based dysplasia severity index with the spheric cup method in the evaluation of adult and adolescent acetabular dysplasia. J Health Sci Med 2021; 4(3): 358-365.

ABSTRACT

Aim: Defining and treating adult and adolescent acetabular dysplasia before arthrosis develops is one of the basic principles of hip-preserving surgery. During the evaluation of cases with asymptomatic or mild symptoms, the severity of the acetabular covering deficiency directs the treatment. We attempted to find answers to two questions with our study: 1) Are the values revealed by the described measurement technique sufficient to detect acetabular dysplasia? 2) Do the criteria calculated by the current technique correlate with the well-known radiological criteria for acetabular dysplasia?

Material and Method: Eighteen hips of patients who had undergone periacetabular osteotomy evaluated by computed tomography (CT) between June 2009 and February 2019 were included in the study (Group 1, dysplasia group). Eighteen patients of similar age and sex, who had tomography examination from the pelvic region, except for orthopedic reasons, were identified between the same dates (Group 2, control group). In the tomography examinations of the patients, the entrance area of the acetabulum was determined using the multiplanar reformation (MPR) technique. Acetabulum volume and femoral head volume was calculated according to the spheric cup measurement method. Acetabular index (AI), extrusion index (EI), Sharp angle (SA), lateral center edge angle (LCEA), and anterior center edge angle (ACEA) values were calculated from direct radiography and CT of the patients.

Results: In the comparative analysis between the groups, a significant difference was observed in terms of acetabular volume, VBADSI, AI, EI, LCEA, SA, and ACEA values ($p<0.05$).

Conclusion: Acetabular volume measured using the spheric cup method and the VBADSI proved to be criteria that could contribute to the diagnosis of acetabular dysplasia. It would be appropriate to measure the described method with a larger series to reveal values peculiar to specific communities.

Keywords: Acetabular dysplasia, acetabular volume, femoral head volume, acetabular dysplasia assessment

INTRODUCTION

Developmental dysplasia of hip (DDH) is an important musculoskeletal disease that can cause sequelae in adolescent and adult patient groups, despite developing early diagnosis methods and treatment strategies. Although the treatment can be completed mostly into adulthood with recognition in infancy and early childhood, there are still cases diagnosed in adolescence and adulthood due to borderline acetabular dysplasia. Left untreated, symptomatic acetabular dysplasia in adults and adolescents may result in subluxation, dislocation, or osteoarthritis modification (1-4).

Diagnoses in adult and adolescent acetabular dysplasia can often be made through direct radiography. Several radiological criteria have been determined for this diagnosis.

For radiological evaluation of the severity of acetabular dysplasia, anteroposterior (AP) pelvic radiography and false profile radiographs are often sufficient (5, 6). Evaluation with direct graphs can be conducted by investigating four different characteristics: acetabular depth, acetabular coating, femoral head sphericity and joint compliance (7). Several criteria have been defined especially for the evaluation of adolescent-adult acetabular dysplasia. Criteria associated with acetabular coverage include lateral center edge angle (LCEA) (8), extrusion index (EI) (9), acetabular index (AI) (10), sharp angle (SA) (11), and Lequesne's anterior center edge angle (ACEA) (5).

All of these well-known criteria are measured according to two dimensions. The range of values specified in demographic studies related to existing criteria vary.

Corresponding Author: Mehmet Burtaç Eren, mehmetburtac@hotmail.com
Received: 06.04.2021 **Accepted:** 26.04.2021

Another crucial issue in demographic studies is the different incidental dysplasia rates in different populations (12-16).

In particular, an intermediate value range has been defined for LCEA value. Cases with LCEA values in the 18–24 range are defined as "borderline dysplasia" and require additional investigation to direct their treatment (17-19).

CT can also be used to evaluate acetabular dysplasia to detect accompanying pathologies and to reveal the treatment plan. The evaluation performed using CT is very valuable, especially in patients who are planning pelvic osteotomy (20-23). Additionally, evaluations by modeling with three dimensional (3D) reformatting is also possible, and it has become widespread in recent years.

3D evaluation of acetabular dysplasia enables a more qualified and less error-prone examination compared to two-dimensional (2D) evaluation (23, 24). The lack of standardized technique during the evaluation and the need for additional software limit the contribution of 3D-CT images (25-27).

Since this advanced CT technique tends to cause high radiation exposure, it is recommended to be used only in patients who need further examination. If there is no clinical requirement, especially in young patients, the use of CT technique is not appropriate. Therefore, CT should not be a first-generation diagnostic method in the evaluation of acetabular dysplasia, and in the case of clinical need, the examination decision should be made through a proper cost benefit analysis (28-30). Magnetic resonance imaging (MRI) should be seen as an alternative in evaluating acetabular morphology, especially in the pre-adolescent pediatric patient group (31).

Since the disorder in DDH is in the entire joint, evaluation based solely on examination of acetabular depth can be seen as incomplete and two-dimensional. The effect of a small femoral head in a shallow acetabulum cannot be expected to be the same as the biomechanical effect of an advanced femoral head secondary to DDH. Biomechanical instability created by a shallow acetabulum will lead to an excessive shear force on the chondral surfaces. It may not be an appropriate approach to consider that only the shallowness and vertical position of the acetabular counter surface are effective in this shear force. Of course, there are some criteria that focus on the relationship between the acetabulum and the femoral head. These are EI, LCEA, and ACEA. Although the angular assessment and extrusion rate are calculated in these techniques, which accept the center of the femoral head, the assessment is two-dimensional and is performed without a sense of depth.

Therefore, the ratio of the volume of the femoral head to the volume of the acetabulum as well as the ratio of acetabular coverage may be valuable. Although the covering of the femoral head changes dynamically with femoral head movement, their volume ratio to each other remains constant at all times.

For this purpose, 3D images obtained by using additional software are transferred to personal computers, and spatial investigations can be performed in 3D models (32). These methods, which are difficult to perform continuously in daily practice, have handicaps, such as the need for additional software, its time-consuming nature, and the inability to perform them in standard picture archiving and communication system (PACS) visualization systems.

We aim to evaluate the volumetric areas of the acetabulum and femur through calculations using a CT-based study performed with the MPR technique, which does not require additional software and which can be integrated with many PACS systems. The current study seeks to investigate two questions:

1. Are the values revealed by the described measurement technique sufficient to detect acetabular dysplasia?
2. Do the criteria calculated by the current technique correlate with the well-known radiological criteria for acetabular dysplasia?

Our hypothesis is stated as follows:

Assessment of acetabular volume calculated by spheric cup method and volume-based acetabular dysplasia severity index contributes to determine severity of acetabular dysplasia.

MATERIAL AND METHOD

Patients were evaluated retrospectively after receiving approval was obtained from Tokat Gaziosmanpaşa University Clinical Researchs Ethics Committee (Date: 01.10.2020, Decision No: 20-KAEK-242). The study was conducted in accordance with the principles of the declaration of Helsinki. Among the patients who underwent periacetabular osteotomy between June 2009 and February 2019, 18 patients who were evaluated with a preoperative CT scan were identified (Group 1, dysplasia group). Eighteen patients of similar age and sex, who had tomography examination from the pelvic region, except for orthopedic reasons, were identified between the same dates (Group 2, control group).

Inclusion criteria included the following:

1. Having a periacetabular osteotomy operation with the diagnosis of acetabular dysplasia and having a pelvic CT performed before the surgery
2. Triradiate cartilage being closed
3. Having had a pelvic CT for reasons other than musculoskeletal complaints

Exclusion criteria were as follows:

1. Systemic inflammatory disease
2. Previous acetabulum, proximal femur fracture history
3. Having a hip surgery other than periacetabular osteotomy
4. CT slice thickness>2 mm

Patient Population

Two working groups were formed. Group 1 (dysplasia group) was evaluated and included 18 hips of 14 patients. The patients in this group consisted of patients who were treated with periacetabular osteotomy for acetabular dysplasia and were evaluated preoperatively by CT. The mean age at the time of examination of Group 1 was 20.0 (14-39), and the M/F ratio was 1/17. Relevant data from Group 2 (the control group) was obtained by scanning CT examinations performed in our center between June 2009 and February 2019 due to reasons other than musculoskeletal system complaints. Eighteen hips of 18 patients were included in the study. Patients of similar age group and gender were selected. The mean age at the time of examination of Group 2 was 19.94 (13–38), and the M/F ratio was 1/18.

The ages, gender, and parties of the patients during the CT examination were recorded.

Acetabular volume, acetabular surface area, femoral head volume, and femoral head surface area were measured during the patients' CT examinations.

Radiological Technique

Acetabular-Femoral Volume Measurement technique: The PACS program was used for all measurements (Sectra Workstation IDS7, Version 21.2.11.6289, ©2019 Sectra AB).

Steps to measure acetabular volume:

1. MPR technique was performed by finding the section containing the fossa acetabulum through the pelvic CT sections containing the acetabulum (**Figure 1a**).
2. The reformatted section line (orange line) was created in the axial plane in contact with the acetabular rim anterior and posterior (**Figure 1b**).
3. Then, the section plan was rotated so that it passed through the superior and inferior border of the acetabulum in the coronal plane section (**Figure 1c**).
4. The measurement was made in the foreground and background in accordance with the cross-section line in the axial plane (green line, A), and this measurement was confirmed by the measurement in the posteroinferior and anterosuperior area, which was made such that it passed through the center of a circle that touched each area of the area where the three components of the acetabulum were seen in the sagittal plane (**Figure 1d**). The radius of the hemispheric vessel bottom circle was calculated by taking half of the measured distance. (α) It was also recorded by measuring the distance between the deepest point of the acetabulum and the first line drawn in the axial section (**Figure 1d**).
5. The acetabulum volume was calculated with the spheric cup volume calculation method (34) using the h and α variables (**Figure 1e**).

Acetabular volume (VA)= $\frac{1}{6}\pi h(3a^2 + h^2)$

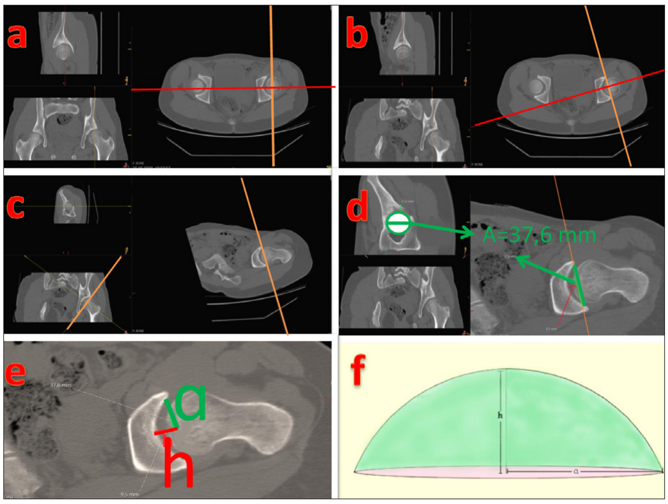

Figure 1. Calculation of acetabular volume using the multi-planar reformatting technique using the spheric cup method

Steps to measure femoral head volume:

1. First, the section where the femoral head appeared as spherical in axial sections was selected. Then, section lines were placed in the center of the femoral head section (**Figure 2a**).
2. The reformatted section line (orange line) was positioned in the middle of the femoral neck in the coronal sections. The other reformatted section line (yellow line) was positioned in the center of the femoral head. It should be noted that sections passed through the center of the spherical head drawn in each plane (axial, coronal, and sagittal) at this stage (**Figure 2b**).
3. When the appropriate cross-sectional area was reached, the radius (r) was calculated by drawing a circle (green circle) per femur to make calculations in the femoral coronal sections. Then, a line was drawn in such a way that the areas where the femoral head sphericity ended were combined medially and laterally, and the exact center of this line length was determined. Half of this line was calculated (red line) and this value was recorded as. The femoral head was extended (blue line) to the point where

the perpendicular drawn from the middle of the line defining the sphericity boundary in the medial and lateral direction intersected the circle. This was the height (h) of the imaginary spheric cup outside the femoral head (**Figure 2c**).

4. The volume of the imaginary femoral sphere (taffy pink colored) was calculated using the r value. The spheric cup volume of the area outside the femoral head joint face (bitter lime neon green colored area) was then calculated. The volume value was determined by subtracting the spheric cup volume from the volume of the femoral head sphere (34) (**Figure 2d**).

Femoral head volume (VFH): $\left(\frac{4}{3}\pi r^3\right) - \left(\frac{1}{6}\pi h(3a^2 + h^2)\right)$

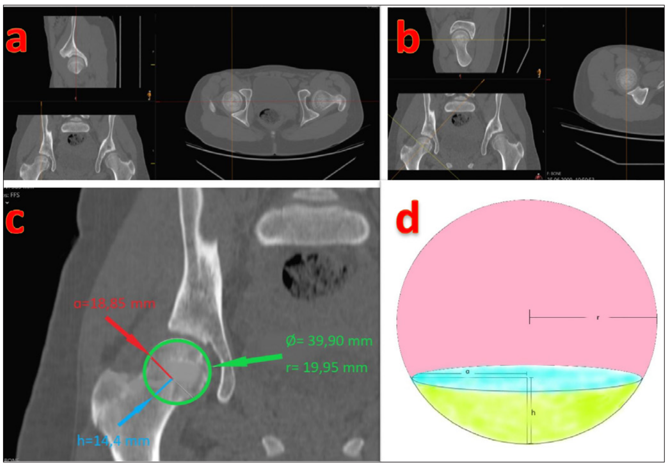

Figure 2. Calculation of the femoral head volume with the spheric cup method using the multi-planar reformatting technique

A new index was defined by comparing the values found to determine the severity of acetabular dysplasia.

Volume-based acetabular dysplasia severity index

VBADSI= $\frac{\text{Femoral head volume } (V_{FH})}{\text{Acetabular volume } (V_A)}$

Other radiological assessment:

The examined radiographic parameters were the AI (10), EI (9), SA (11), Wiberg's lateral center edge angle (LCEA) (8), and Lequesne's ACEA (5) (**Figure 3**).

In Group 1, radiological evaluation was performed with AP pelvis graphy-false profile graph. Patients in Group 2 did not have false profile graphs because the reason for application was not associated musculoskeletal complaints. For this reason, the false profile graph was obtained by processing the 3D reformats of the CT examinations.

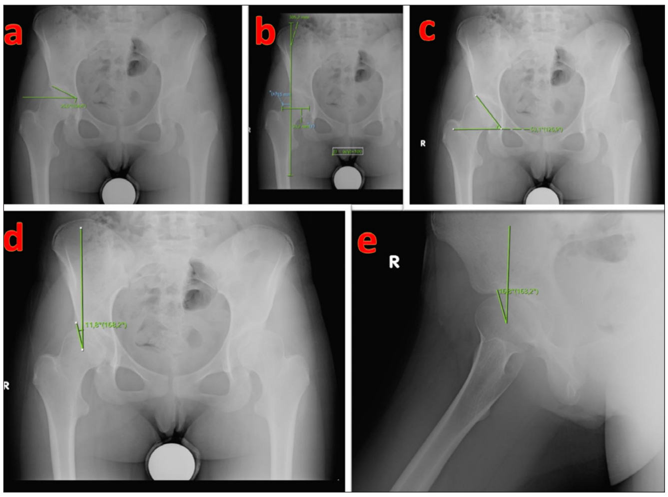

Figure 3. Radiological measurements of the hip joint. **a)** Acetabular index **b)** Extrusion Index(EI) measurement= X: Horizontal length of the femoral head not covered by acetabulum,W: diameter of femoral head, EI=(X/W)x100. **c)** Sharp angle **d)** Wiberg's Lateral Center Edge Angle(LCEA) **e)** Lequesne Anterior Center Edge Angle(ACEA) in "false profile" view

In order to obtain a false profile image with 3D reconstruction, the pelvis bone was reconstructed in 3D. First, looking from the top (**Figure 4a**), a circle that would be the central lumbar vertebra corpus was drawn, and the degree of rotation was determined angularly. With reference to the posterior spinous process, 25° of rotation was achieved as in positioning to the false profile (**Figure 4b**). The false profile graph was taken to the shooting position by rotating the pelvis in rotation in the vertical direction in the AP plan (**Figure 4c**). Then, it was processed again on the computer to create an X-ray image (**Figure 4d**). Angle measurement was performed from the obtained false profile graph. A ready-made PACS program was used for all measurements (Sectra Workstation IDS7, Version 21.2.11.6289, © 2019 Sectra AB). All volumetric measurements and radiographic parameters were assessed and computerized by one observer (MBE).

During the examination, differences between the groups in terms of age, gender, side, acetabular volume, femoral head volume, VBADSI, AI, EI, SA, LCEA, and ACEA were tested. In addition, the correlation between acetabular volume, femoral head volume, VBADSI, and other well-known radiological criteria were evaluated.

Statistical Analysis

Descriptive analyses were made to provide information regarding the general characteristics of the study groups. The data of continuous variables were expressed as mean±standard deviation. Data for categorical variables were expressed as n(%). Normality assumption was analyzed using the Shapiro-Wilk test. While comparing the means of quantitative variables between groups, the test of significance of the difference between two averages was used. Pearson correlation coefficient was used for the relationship between quantitative variables. p<0.05 was considered as statistically significant. Ready-made statistics software was used for calculations (SPSS 22.0 Chicago, IL, USA).

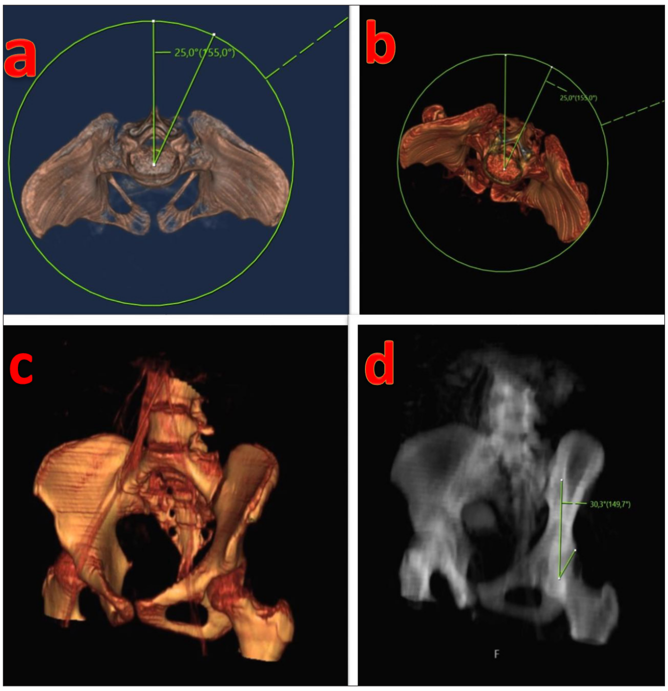

Figure 4. Obtaining a false profile image with 3D reconstruction: **a)** looking from the top, a circle that would be the central lumbar vertebra corpus was drawn, and the degree of rotation was determined angularly, **b)** with reference to the posterior spinous process, 25° of rotation was achieved as in positioning to the false profile, **c)** false profile position has been set, **d)** software reconstruction has realized to create an X-ray image

RESULTS

A significant difference was observed between the groups in terms of acetabular volume, VBADSI, AI, EI, LCEA, SA, and ACEA values (p<0.05) (**Table 1**) (**Figure 5**).

Table 1. Distribution of variables between groups

	Group 1 (Dysplastic) Avg.±SD	Group 2 (Non-dysplastic) Avg.±SD	p
Age year	20±6.77	19.94±6.51	0.980
Acetabular volume mm³	13453.44±3490.36	17415.22±5704.56	0.017*
Femoral head volume mm³	36339.67±12108.21	34646.28±7697.65	0.620
VBADSI	2.83±1.11	2.14±0.66	0.030 *
AI°	34.62±4.52	18.34±4.37	<0.001*
EI (%)	37.27±6.87	14.46±3.8	<0.001*
LCEA°	13.23±6.31	32.62±7.05	<0.001*
Sharp angle°	51.66±4.1	41.52±2.84	<0.001*
ACEA	18.13±4.95	30.21±5.67	<0.001*

*Statistically significant (p<0.05)

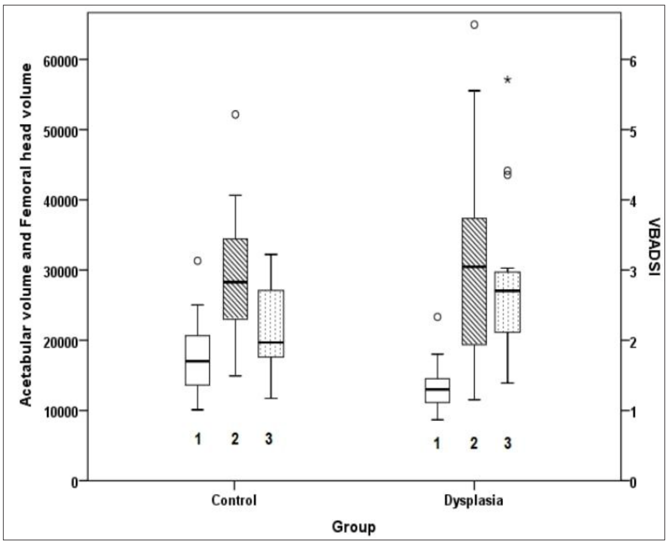

Figure 5. Box plot showing the distribution of acetabular volume, femoral head volume and VBADSI
[1]:Acetabular volume; [2]:Femoral head volume; [3]: VBADSI

With the variables whose measurement technique is defined in the article; In evaluation for the correlation between well-known acetabular surface coverage markers such as AI, EI, LCEA Sharp Angle, and ACEA:

A correlation was observed between acetabular volume and AI and EI values (**Table 2**).

Table 2. Correlation between variables

		AI	EI	LCEA	Sharp angle	ACEA
Acetabular volume	r	-0.459	-0.336	0.275	-0.125	0.270
	p	0.005*	0.045*	0.105	0.468	0.112
Femoral head volume	r	-0.083	-0.047	0.100	-0.028	-0.068
	p	0.630	0.785	0.562	0.871	0.694
VBADSI	r	0.263	0.214	-0.157	0.063	-0.233
	p	0.121	0.209	0.360	0.713	0.172

*Statistically significant (p<0.05)
"r value" represents the strength of the relationship. Positive values are associated with direct proportions, negative values are associated with inverse proportions.

DISCUSSION

This study focuses on investigating the effectiveness of evaluating the severity of acetabular dysplasia with a newly developed measurement technique. Our study revealed that acetabular volume and VBADSI may be indicators of acetabular dysplasia severity.

The main result of our study was the significant difference in acetabular volume and VBADSI between age and side randomization groups. This result suggests that acetabular volume and VBADSI measured by the current technique were valuable criteria that could be used in defining severity of acetabular dysplasia.

Most of the studies evaluating acetabular dysplasia with CT were performed using the 3D reconstruction technique (23,27,33-36). Among these studies, those performed with the 3D reconstruction technique generally compared direct radiographs and MPR angle measurements. Chadayammur et al. (37) in their prospective study compared the LCEA angle they obtained in CT coronal reformates with the measurements made on standard AP radiographs. In their studies, in which sub-evaluations were performed according to the diagnoses of the patients, they revealed significant differences in the measurements made with CT and direct radiographies, especially in the CAM-type femoroacetabular impingement patient group accompanied by acetabular dysplasia. This leads us to believe that one dimensional radiological evaluation of the acetabulum that demonstrate significant anatomical differences secondary to dysplasia may be insufficient. In our study, the difference in acetabular volume and VBADSI values obtained as a result of the 3D evaluation performed by measuring the acetabulum and femoral head volume in the dysplastic patient group suggested that these criteria could be used in dysplasia complicated with femoroacetabular impingement.

Mimura et al. (26) in studies evaluating the incidence of acetabular dysplasia in a Japanese population performed acetabular dysplasia assessment in the axial, coronal, and sagittal planes using the MPR method. When all three plans were evaluated together, they found that the prevalence of acetabular dysplasia was at least twice as high as compared to evaluation alone. In our study, the spheric cup method, which we implemented by taking into account both 3 dimensions with MPR, enabled us to evaluate the acetabulum as a dome section. We believe that we have conducted the evaluation of acetabular dysplasia in three dimensions with our study, which we modeled by evaluating the base of a spheric cup in three planes.

In another study in which acetabular dysplasia was evaluated in 3D, Ito et al. (32) examined dysplasia in five different groups according to the direction of the lack of covering. Whereas there was no significant difference between the clinical scores between the groups, they revealed that there was a correlation between clinical scores and the amount of coverage. Although the clinical scores of the patients were not evaluated in our study, comparison between the groups has showed the significant difference in acetabular volume and VBADSI.

In our study, unlike the current literature, volumetric evaluation was made with the MPR technique. Of course, the morphology of a dysplastic acetabulum will not be in the form of a spheric cup in relation to the differences in the areas where the coverage is reduced.

We believe that our measurement technique was a more approximate estimation method. However, considering that our volume calculation, which we obtained with a more practical method, was easy to apply and did not require additional software, it may be viewed as more advantageous in terms of clinical applications.

Furthermore, the results of present the study also demonstrated that acetabular volume value was correlated with AI and EI values. This leads us believe that they can be used in diagnosis as well as the well-known acetabular dysplasia criteria. It may be appropriate to use these criteria, especially for remodelization follow-up after diagnosis and surgery.

Our study results revealed that the acetabular volume assessment performed with the spheric cup method and the assessment of the VBADSI, in accordance with our hypothesis, contribute to proper diagnosis. The purpose of defining the method described is not to create an alternative to more precise measurement methods but to provide an approach that can be used in daily practice without additional software. With the methods described, a global assessment of dysplasia severity and a practical volume measurement proposal has been presented. The direction and regional analysis of dysplasia has recently gained importance in the evaluation of acetabular dysplasia. It is clear that 3D reconstruction will offer a more spatial evaluation opportunity to evaluate the disparities between anterior, lateral, and posterior coverage, and it will be more useful in such analyses.

The main limitations of our study include the small sample size and the measurement of acetabulum-femoral head volume with an approximate method. Similarly, when we consider that the volume of the femoral head is measured with the same method, we believe that this neglected volumetric difference is not clinically significant, especially in terms of the acetabular dysplasia severity volume index. Considering that CT indication is used for acetabular osteotomy planning in acetabular dysplasia, we observed that the number of patients with symptomatic acetabular dysplasia CT was limited. The possible reason for this is that we want to protect our patients in the reproductive age and adolescent age group from radiation exposure. For this newly defined measurement technique, we believe that these limitations did not affect the results of the study directly.

Although conventional 2D techniques are often sufficient to diagnose acetabular dysplasia, acetabulum volume-surface measurements can provide valuable information, especially in patients with borderline dysplasia. With the spheric cup method, acetabular volume, and VBADSI can be viewed as a safe and valuable alternative dysplasia scale.

CONCLUSION

The findings of our study suggest that the VBADSI and acetabular volume that we measured with the spheric cup method could be valuable in evaluating the severity of acetabular dysplasia. Since the current method can be performed practically without the need for additional software and hardware other than the standard PACS systems, it appears easier to perform compared to similar volumetric analysis. It is clear that studies that evaluate the reliability and validity of the described technique in different populations and which compare them with 3D modeling and volume calculating methods will be needed.

ETHICAL DECLARATION

Ethics Committee Approval: Approval was obtained from Tokat Gaziosmanpaşa University Clinical Researchs Ethics Committee (Date: 01.10.2020, Decision No: 20-KAEK-242).

Informed Consent: Because the study was designed retrospectively, no written informed consent form was obtained from patients.

Referee Evaluation Process: Externally peer-reviewed.

Conflict of Interest Statement: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declare that this study has received no financial support.

Author Contributions: All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved its final version.

REFERENCES

1. Gala L, Clohisy JC, Beaulé PE. Hip dysplasia in the young adult. J Bone Joint Surg Am 2016; 98: 63-73.
2. Domb BG, Stake CE, Lindner D, El-Bitar Y, Jackson TJ. Arthroscopic capsular plication and labral preservation in borderline hip dysplasia: two-year clinical outcomes of a surgical approach to a challenging problem. Am J Sports Med 2013; 41: 2591-8.
3. Malvitz TA, Weinstein SL. Closed reduction for congenital dysplasia of the hip. Functional and radiographic results after an average of thirty years. J Bone Joint Surg Am 1994; 76: 1777-92.
4. Murphy SB, Ganz R, Müller M. The prognosis in untreated dysplasia of the hip. A study of radiographic factors that predict the outcome. J Bone Joint Surg Am 1995; 77: 985-9.
5. Lequesne M. Le faux profile de bassin. Nouvelle incidence radiographique pour l'etude de la hanche. Son utilite dans les differentes coxopathies. Rev Rhem Malosteoartic 1961; 28: 643-52.
6. Millis MB, Kim YJ. Rationale of osteotomy and related procedures for hip preservation: a review. Clin Orthop Relat Res 2002; 405: 108-21.
7. Tannast M, Siebenrock KA, Anderson SE. Femoroacetabular impingement: radiographic diagnosis-what the radiologist should know. Am J Roentgenol 2007; 188: 1540-52.
8. Wiberg G. Studies on dysplastic acetabula and congenial subluxation of the hip joint. Acta Chir Scand Suppl 1939; 83: 1-130.
9. Li PL, Ganz R. Morphologic features of congenital acetabular dysplasia: one in six is retroverted. Clin Orthop Relat Res 2003; 416: 245-53.
10. Hilgenreiner H. Zur fuhdiagnose und fruhbehandlung der angeboren huftgelenkverrenkung. Med Klin 1925; 21: 1425-29.
11. Sharp IK. Acetabular dysplasia: the acetabular angle J Bone Joint Surg Br 1961; 43: 268-72.
12. Umer M, Thambyah A, Tan W, De SD. Acetabular morphometry for determining hip dysplasia in the Singaporean population. J Orthop Surg 2006; 14: 27-31.
13. Han CD, Yoo JH, Lee WS, Choe WS. Radiographic parameters of acetabulum for dysplasia in Korean adults. Yonsei Med J 1998; 39: 404-8.
14. Aktas S, Pekindil G, Ercan S, Pekindil Y. Acetabular dysplasia in normal Turkish adults. Bull Hosp Jt Dis Orthop Inst 2000; 59: 158-62.
15. Yoshimura N, Campbell L, Hashimoto T, et al. Acetabular dysplasia and hip osteoarthritis in Britain and Japan. Rheumatology 1998; 37: 1193-7.
16. Kim C-H, Park JI, Shin DJ, Oh SH, Jeong MY, Yoon PW. Prevalence of radiologic acetabular dysplasia in asymptomatic Asian volunteers. J Hip Preserv Surg 2019; 6: 55-9.
17. Wyatt MC, Beck M. The management of the painful borderline dysplastic hip. J Hip Preserv Surg 2018; 5: 105-12.
18. McClincy MP, Wylie JD, Kim YJ, Millis MB, Novais EN. Periacetabular osteotomy improves pain and function in patients with lateral center-edge angle between 18° and 25°, but are these hips really borderline dysplastic? Clin Orthop Relat Res 2019; 477: 1145.
19. Bixby SD, Millis MB. The borderline dysplastic hip: when and how is it abnormal? Pediatr Radiol 2019; 49: 1669-77.
20. Azuma H, Taneda H, Igarashi H, Fujioka M. Preoperative and postoperative assessment of rotational acetabular osteotomy for dysplastic hips in children by three-dimensional surface reconstruction computed tomography imaging J Pediatr Orthop 1990; 10: 33-8.
21. Haddad FS, Garbuz DS, Duncan CP, Janzen DL, Munk PL. CT evaluation of periacetabular osteotomies. J Bone Joint Surg Br 2000; 82: 526-31.
22. Mechlenburg I, Nyengaard J, Rømer L, Søballe K. Changes in load-bearing area after Ganz periacetabular osteotomy evaluated by multislice CT scanning and stereology. Acta Orthop Scand 2004; 75: 147-53.
23. Nakamura S, Yorikawa J, Otsuka K, Takeshita K, Harasawa A, Matsushita T. Evaluation of acetabular dysplasia using a top view of the hip on three-dimensional CT. J Orthop Sci 2000; 5: 533-9.
24. Humbert L, Carlioz H, Baudoin A, Skalli W, Mitton D. 3D Evaluation of the acetabular coverage assessed by biplanar X-rays or single anteroposterior X-ray compared with CT-scan. Comput Methods Biomech Biomed Engin 2008; 11: 257-62.
25. Zhang S, Zhang G, Peng Y, Wang X, Tang P, Zhang L. Radiological measurement of pelvic fractures using a pelvic deformity measurement software program. J Orthop Surg Res 2020; 15: 37.
26. Mimura T, Mori K, Kitagawa M, et al. Multiplanar evaluation of radiological findings associated with acetabular dysplasia and investigation of its prevalence in an Asian population: a CT-based study. BMC Musculoskelet Disord 2017; 18: 50.
27. Jóźwiak M, Rychlik M, Musielak B, Chen BPJ, Idzior M, Grzegorzewski A. An accurate method of radiological assessment of acetabular volume and orientation in computed tomography spatial reconstruction. BMC Musculoskelet Disord 2015; 16: 42.
28. Israel GM, Cicchiello L, Brink J, Huda W. Patient size and radiation exposure in thoracic, pelvic, and abdominal CT examinations performed with automatic exposure control. Am J Roentgenol 2010; 195: 1342-6.

29. Griffey RT, Sodickson A. Cumulative radiation exposure and cancer risk estimates in emergency department patients undergoing repeat or multiple CT. Am J Roentgenol 2009; 192: 887-92.

30. Arapakis I, Efstathopoulos E, Tsitsia V, et al. Using “iDose4” iterative reconstruction algorithm in adults’ chest–abdomen–pelvis CT examinations: effect on image quality in relation to patient radiation exposure. Br J Radiol 2014; 87: 20130613.

31. Ozgur AF, Aksoy MC, Kandemir U, et al. Does Dega osteotomy increase acetabular volume in developmental dysplasia of the hip. J Pediatr Orthop B 2006; 15: 83-6.

32. Ito H, Matsuno T, Hirayama T, Tanino H, Yamanaka Y, Minami A. Three-dimensional computed tomography analysis of non-osteoarthritic adult acetabular dysplasia. Skelet Radiol 2009; 38: 131-9.

33. Irie T, Orias AAE, Irie TY, et al. Computed tomography-based three-dimensional analyses show similarities in anterosuperior acetabular coverage between acetabular dysplasia and borderline dysplasia. Arthroscopy 2020; S0749-8063(0720)30482-30485.

34. van Bosse H, Wedge JH, Babyn P. How are dysplastic hips different? A three-dimensional CT study. Clin Orthop Relat Res 2015; 473: 1712-23.

35. Dandachli W, Kannan V, Richards R, Shah Z, Hall-Craggs M, Witt J. Analysis of cover of the femoral head in normal and dysplastic hips: new CT-based technique. J Bone Joint Surg Br 2008; 90: 1428-34.

36. Nepple JJ, Wells J, Ross JR, Bedi A, Schoenecker PL, Clohisy JC. Three patterns of acetabular deficiency are common in young adult patients with acetabular dysplasia. Clin Orthop Relat Res 2017; 475: 1037-44.

37. Chadayammuri V, Garabekyan T, Jesse MK, et al. Measurement of lateral acetabular coverage: a comparison between CT and plain radiography. J Hip Preserv Surg 2015; 2: 392-400.