Original article
https://doi.org/10.18019/1028-4427-2025-31-6-813-821

Establishing boundaries of acetabular walls in total hip replacement

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Abstract

Introduction The term "acetabular walls" is used to describe the survival rate of total hip replacements (THR) and classifications of THR surgeries. With the experience accumulated in THR surgery, there is no information on establishing boundaries of the acetabular walls. ASPID is a classification system used to describe post-traumatic acetabular deformities with no technique for establishing boundaries of acetabular walls.

The **objective** was to demonstrate and provide a theoretical substantiation for a method establishing the boundaries of the acetabular walls in primary THR.

Material and methods Pelvic computed tomography scans of five children aged 10–12 years and 30 pelvic preparations of adult bones without signs of acetabular dysplasia were used.

Results Extraacetabular fixed anatomical landmarks were identified in 3D models from CT scans of pediatric pelvic bones with the planes dividing acetabulum into conditional walls separated by cartilage. The pelvic bones of 30 adults were scanned, and similar reconstructions performed to delineate boundaries of the acetabular walls. The proportional ratios and areas of each acetabular wall were determined in the pediatric and adult groups, and the results compared. The absence of statistical differences in the proportions of the superior, posterior and medial walls of the pediatric and adult acetabulum suggested high reliability of the method.

Discussion There were insignificant statistical differences in the anterior acetabular wall fraction of children and adults and could be associated with a small quantity of measurements. The absence of statistical differences in the proportions of the superior, posterior and medial walls of the pediatric and adult acetabulum suggested the reliability of the method. A larger number of measurements to be performed by several specialists, determination of the Cohen's Kappa coefficient and statistical analysis of the results are essential for the validity of the method.

Conclusion The method offered for establishing boundaries of the acetabular walls can be practical for scientific research, but cannot be used in routine practice due to its complexity and the need to use special software. The method can be recommended for describing post-traumatic deformities of the acetabular walls in cases where extraacetabular landmarks are not damaged or displaced.

Keywords: acetabulum, total hip replacement, posttraumatic deformity, walls, ASPID

For citation: Tsybin AV, Lyubchak VV, Falkovich AS, Bilyk SS, Baskov VE, Gayvoronskiy IV. Establishing boundaries of acetabular walls in total hip replacement. *Genij Ortopedii*. 2025;31(6):813-821. doi: 10.18019/1028-4427-2025-31-6-813-821.

INTRODUCTION

Hip replacement surgery is a treatment option for hip injuries and diseases and aims to relieve pain, restore function and improve quality of life. Hip replacement surgery was first performed in 1960 [1]. Short- and long-term outcomes, complications of the surgical procedure have been published in numerous articles since then [2, 3, 4].

The bone condition is one of the main factors for reliable primary implant fixation and survival of the artificial joint. The term "acetabular walls" was introduced to describe surgical technique, analyze long-term results and complications, and classify cases of primary and revision THR. The term can be encountered in publications reporting THR survival and in classifications of hip replacement surgeries [5–12]. This definition relies on the theoretical aspects of THR, but the use of the term “acetabular walls” provides no clarification regarding their boundaries. Anisimova et al. reported parameters of the acetabulum in details to include the thickness of the walls, without specifying the boundaries of the latter [13]. AO classification of acetabular fractures grades injury to the columns and to the walls of the acetabulum with the boundaries of the walls being not defined within the fracture assessment system [14]. There are a large number of works reporting the AO classification, the causes, treatment and consequences of pelvic and acetabular fractures, injury to the columns and acetabular walls with no information on the boundaries of the acetabular walls to be determined [15–22].

The authors of the Russian patent dated December 28, 2020 "A method for selecting surgical strategy depending on the degree of acetabular deformity and the integrity of the pelvic ring in patients with post-traumatic coxarthrosis," offered an original classification of post-traumatic acetabular deformities ASPID based on three criteria, including the deformity localization (anterior, superior, posterior, and medial walls of the acetabulum). The classification had no description of the method for determining the boundaries of the above walls [23, 24].

Outcomes of THR performed for stage 3 post-traumatic hip arthritis with acetabular wall deformities are significantly worse than those resulting from other causes. These cases are not classified according to acetabular wall defects due to the lack of a specific classification, making it difficult to accurately analyze the causes of failures [25, 26]. Although the method for determining the boundaries of the acetabular walls and localization of the boundaries during THR has not been described, the concept of “acetabular walls” exists and is widely used.

The **objective** was to demonstrate and provide a theoretical substantiation for a method establishing the boundaries of the acetabular walls in primary THR.

MATERIAL AND METHODS

Pelvic computed tomography scans of five children aged 10–12 years and 30 pelvic preparations of adult bones without signs of acetabular dysplasia were used.

Special computer programs: Materialise Mimics Research 21.0 and Materialise 3-matic Research 13.0 were used to create 3D models and analyze them, identify necessary landmarks, construct planes and divide the acetabulum into walls.

The landmarks were defined so that the lines drawn through them during 3D modeling based on CT scans in adults were close to the lines of incomplete osteogenesis dividing the walls of the acetabulum in children (Fig. 1).

The first stage of the study included analysis of pediatric CT scans of pelvic bones, construction of 3D models of the pelvic bones, and determination of extraacetabular fixed anatomical landmarks

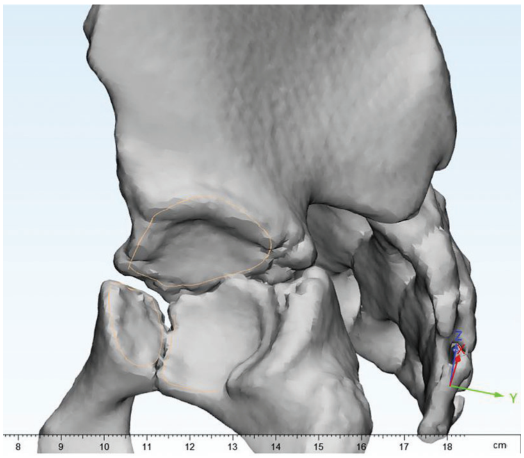

Fig. 1 An instance of a 3D model of a pediatric pelvis

to draw planes and divide the pediatric acetabulum into conditional walls separated by cartilage.

Based on computed tomography of the pelvic bones, a high-precision three-dimensional surface was formed with the points to be marked: the most prominent point of the pubic tubercle (1); the most prominent point on the pubic crest (2); the most prominent point of the ischial tuberosity (3) and the most prominent point of the anterior inferior iliac spine (4). The acetabular outlet plane was formed: the two most prominent points of the acetabular notch (5, 6) and a point on the superior wall of the acetabulum (7), obtained by drawing a perpendicular from the midpoint of the transverse ligament line to the superior wall. Next, the center point of the acetabulum was determined on the plane of the exit (9), — the maximum transverse diameter of the acetabulum and the distance, divided in half. Further construction of planes was performed relative to the plane of the acetabulum exit and the point (the center of the acetabulum) obtained by drawing a line through the center of the acetabulum, perpendicular to the plane of the acetabulum exiting to the medial wall (8) (Fig. 2).

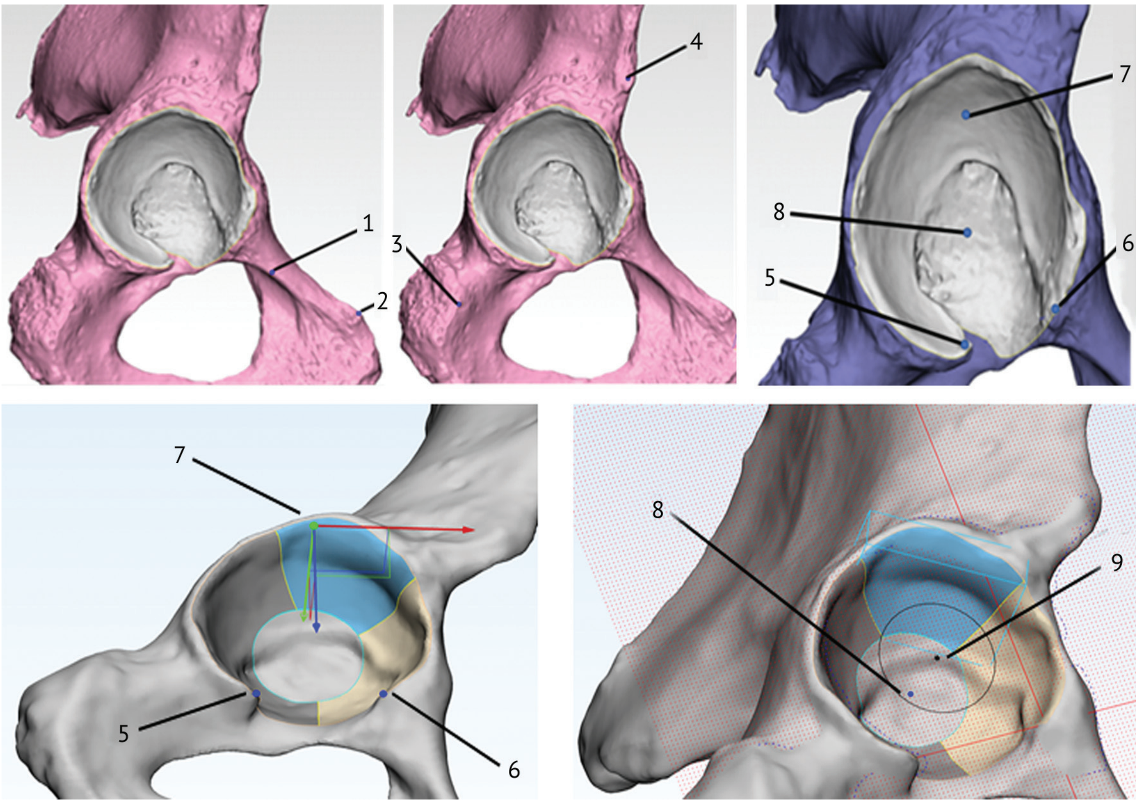

Fig. 2 Marking points on a 3D model of the acetabulum

The planes were constructed using points located directly on the triangular mesh of the computer model and freely in the 3D coordinate system. Materialise 3-matic Research 13.0, a 3D modeling application with reverse engineering functionality, was used to construct the planes (three points are the minimum necessary and sufficient number to construct a plane in a three-dimensional coordinate system). The projection of a circle (Fig. 2 shows a diagram with a plane and a circle) onto the wall of the acetabulum was constructed using the planar drawing function with the projection lines being superimposed on the surface of the triangulation model at the required angle (the function is included in the computer program). The acetabular boundaries were defined using a tool for dividing the main mesh into individual surfaces by specifying a series of points that were subsequently connected into a single closed line.

The first plane was formed by the center of the acetabulum, the most prominent point of the pubic tubercle and the most prominent point on the pubic crest (Fig. 3, plane 1). The second plane was formed by the center of the acetabulum, the most protruding point of the ischial tuberosity and the most protruding point of the anterior inferior iliac spine (Fig. 3, pl. 2).

A circle with a radius equal to ¼ of the maximum transverse diameter was formed From the center of the acetabulum parallel to the plane of the exit (this is how the medial wall was projected). A line segment connecting the two most prominent points of the acetabular notch was constructed. A point was placed in the middle, which was projected parallel to the plane of the acetabulum exit onto the medial wall (Fig. 3, point 10). Using an additional third point, a plane was obtained (Fig. 3, plane 3) dividing the fragment of the lower part of the acetabulum into anterior and posterior sections, which finally allowed formation of the anterior, posterior, superior and medial walls (Fig. 4).

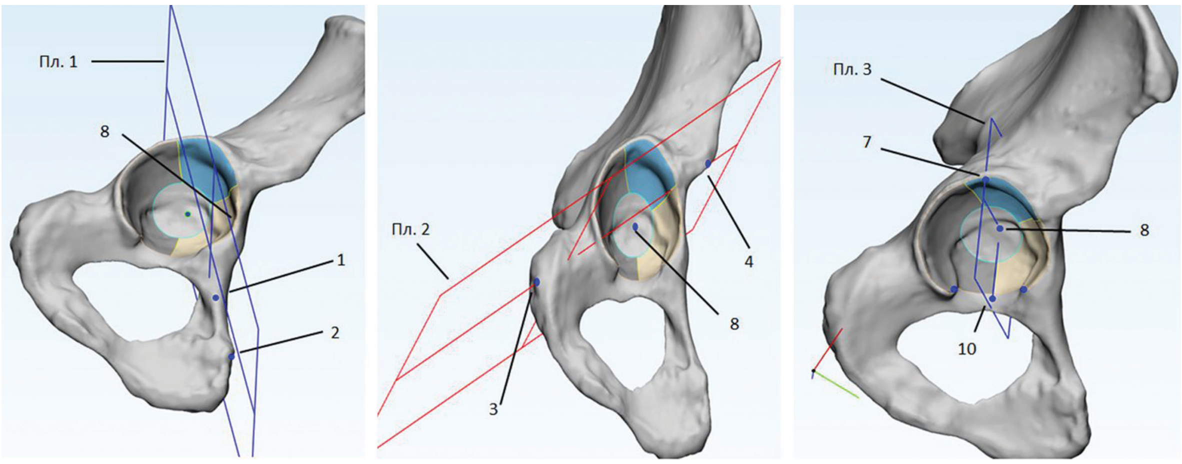

Fig. 3 Division of the acetabulum using planes

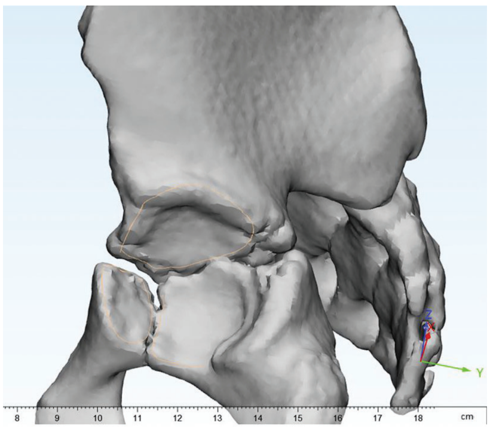

Fig. 4 The acetabulum divided into anterior, superior, posterior and medial walls following analysis of a 3D model of the pelvis

Scanning of the adult pelvis and conducting similar constructions was performed at the second stage to draw the boundaries of the acetabulum walls.

The proportional ratio and area of each wall of the acetabulum was determined in groups of children and adults at the third stage comparing the results and identifying measurement errors with a subsequent conclusion on the possible validity of the method. The total area of the acetabulum (mm), the areas of each acetabular wall, and their proportions relative to the total area were calculated in the cases using Materialise 3-matic Research 13.0. The results are tabulated for comparison of the data to determine the validity of the original method of dividing the acetabulum into “walls” in THR.

One-way analysis of variance, a nonparametric evaluation method, the Mann – Whitney rank test (U-test, Wilcoxon – Mann – Whitney test) were used for statistical analysis for testing the hypothesis about the difference between two samples, U-statistics U_1 and U_2 according to the formulas:

$$U_1 = n_1 \cdot n_2 + \frac{n_1(n_1+1)}{2} - R_1;$$

$$U_2 = n_1 \cdot n_2 + \frac{n_2(n_2+1)}{2} - R_2,$$

where n_1 and n_3 are the number of adults and children examined, respectively

RESULTS

One-way analysis of variance showed no statistical differences in the ratios of the percentage shares of the superior, posterior and medial walls relative to the total surface area of the acetabulum in adults and children (Table 1) confirming the validity of the method. There were slight differences in the parameters for the anterior wall due to the small number of measurements in the samples.

Table 1

One-way analysis of variance (comparison of the means in two samples)

Description	A (%)	S (%)	P (%)	I (%)
Adults (30 measurements)				
The mean	25.79	24.54	35.31	14.38
Standard deviation	2.63	3.55	3.21	1.01
Error of the mean	0.48	0.65	0.59	0.18
Children (5 measurements)				
The mean	30.08	23.02	32.10	14.80
Standard deviation	3.10	4.51	5.46	2.73
Error of the mean	1.39	2.01	2.44	1.22
Difference between means	4.30	1.52	3.20	0.41
Difference error	1.47	2.12	2.51	1.23
The ratio of the difference to the error of the difference	2.93	0.72	1.27	0.33

Note: A, anterior wall; S, superior wall; P, posterior wall; I, medial wall.

The data in the last row (the ratio of the difference to the error of the difference) were compared with the table value of the Student's t-distribution at a significance level of 0.05 with 32 (30 + 5 – 3) degrees of freedom, which was equal to 2.037. If the number obtained was greater than the table value (2.037) it was considered that the data in the two samples differed, as at wall "A". In the remaining three cases (S, P, I) the numbers obtained were less than 2.037 with no differences between the adult and child samples.

A similar result was obtained using a nonparametric evaluation method the Mann – Whitney U-test (Wilcoxon – Mann – Whitney test). The percentages of each acetabular wall were compared separately in the samples. The data from both samples were combined and sorted (ranked) in ascending order for each percentage (A, S, P, I). A sequential number ("rank") was assigned for each subject. Then, the sums of the ranks (R1 for the adult group, R2 for the child group) and the U-statistics U_1 and U_2 were calculated separately for adults and children (Table 2). The smallest of the two numbers obtained $U_e = \min(U_1, U_2)$ was chosen as the Mann – Whitney U statistic.

Table 2

Application of a nonparametric evaluation method the Mann – Whitney rank test

Description	A (%)	S (%)	P (%)	I (%)
Adults (n_1 = 30 measurements)				
Sum of ranks R_1	483	561	569	542
U_1	132	54	46	73
Children (n_2 = 5 measurements)				
Sum of ranks R_2	147	69	61	88
U_2	18	96	104	77
Table value of the Mann–Whitney statistic at a confidence level of 0.05	39			

Note: A, anterior wall; S, superior wall; P, posterior wall; I, medial wall.

If the statistic Mann – Whitney value of Ue was less than the table value (for example, when measuring the percentage of the "A" wall), the null hypothesis of no difference between the two samples was rejected and the alternative hypothesis was accepted, that is, the difference between the two samples was considered statistically significant. There were no differences in the percentages of walls S, P, and I did not differ between the adult and child samples in the remaining three cases. However, the interval diagram below (Fig. 5) shows that the difference in the percentages of wall A between adults and children was not very significant with no difference for walls S, P, and I.

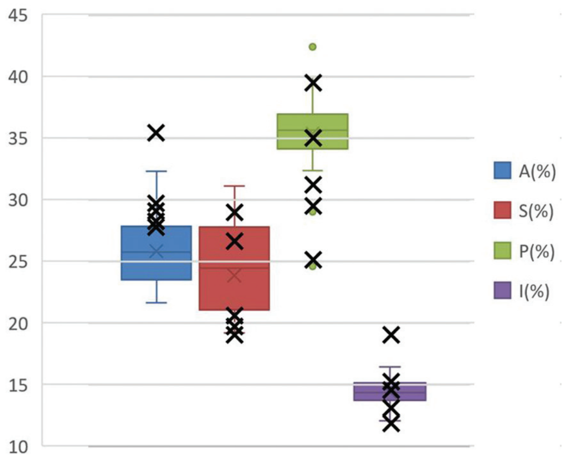

Fig. 5 Interval diagram. Colored elements represent adult data, black diagonal crosses represent children's data. Filled rectangles represent the second and third quartiles, horizontal lines in the middle of the rectangles are the medians, and T-shaped extension lines ("whiskers") indicate maxima and minima, excluding outliers, individual colored dots (on the diagram only for P) are outliers (values that deviate from the main sample array by more than 1.5 interquartile ranges from the nearest quartile)

DISCUSSION

Literature review on various aspects of THR confronts researchers with the concept of "acetabular walls." Given the absence of such a concept in normal anatomy, novice practitioners may encounter a number of contradictions when learning hip arthroplasty techniques and implanting the acetabular component. The problem is not associated with standard primary joint replacement procedures for minor acetabular changes and not related to post-traumatic conditions or congenital pathology with no changes in the bone structure or deformities.

CT scans of the pelvis of 10– to 12–year-old children without signs of hip dysplasia were used to devise the method for the following reason: tt is known that at birth, the acetabular cartilage complex is located between the ilium superiorly, the ischium inferiorly, and the pubic bone anteriorly.

The outer two thirds of the structure form the so-called acetabular cartilage, and its medial third belongs to the medial wall. At puberty (10–12 years), the depth of the acetabulum increases due to the development of three secondary ossification centers. Connolly and Weinstein suggested that the "acetabular bone" (os acetabulum) is a secondary epiphysis of the pubic bone and contributes to the development of the anterior wall of the acetabulum [27]. The epiphysis of the acetabulum is the secondary growth center of the ilium and forms the main part of the superior wall of the acetabulum. The ischium contains a small, innominate secondary growth center, which is involved in the formation of the posterior wall of the acetabulum [28]. Therefore, the walls of the pediatric acetabulum are formed from four ossification centers (one primary and three secondary) at the age of 10–12 years. The walls have not yet fully formed at this age, a clear boundary can be seen between them on CT scans. The observation served the basis for this study to determine the boundaries of the acetabular walls using extraacetabular landmarks.

In cases of traumatic origin, the anatomy of the acetabulum would acquire a unique configuration, which is difficult to describe and systematize due to the lack of a generally accepted assessment system [29]. There is a paucity of publications on THR performed for patients with post-traumatic acetabulum, reporting very small groups of patients with no practical role due to the lack of a generally accepted systemic approach. Primary THR is sometimes used for acute acetabular fractures and implant survival is difficult to evaluate. With no method for determining the acetabular wall boundaries, it is difficult to develop recommendations for the choice of strategy in the patients. Kirkeboe et al. reported 48 patients (mean age 68 years) with acetabular fractures treated with ORIF and acute THR, stabilizing both columns and the acetabular shell with no boundaries and sizes of defects of each acetabular wall during implantation of the acetabular component [30].

Our study is unique and can serve as the basis for a more comprehensive investigation of the acetabulum in congenital and post-traumatic deformities. The statistical results showed high reliability of this method. There were insignificant statistical differences in the fraction of the anterior acetabular wall of the pediatric and adult groups due to the small number of measurements produced in the groups. No statistical differences were found in superior, posterior, and medial acetabular wall fractions between the pediatric and adult groups confirmed the validity of the method. Requires a greater number of measurements to be performed by several specialists, measurement of the Cohen's Kappa coefficient and statistical analysis of the results are required for further evaluation of the validity of the method.

Our work is part of a larger study exploring outcomes of primary THR in patients with stage 3 post-traumatic hip arthritis and post-traumatic acetabular wall deformities. An original acetabular classification system called ASPID was developed for post-traumatic conditions at the Vreden National Medical Research Center for Trauma and Orthopedics by analogy with the TNM system used in oncology. The ASPID system used the walls of the acetabulum as the basis for classification with the concept of acetabular boundaries to be introduced, including theoretical aspects confirming the need to implement an original system for assessing acetabulum after acetabular fractures. An algorithm for selecting surgical strategy is to be developed based on this classification and to be tested on a larger group of patients as part of a multicenter study.

CONCLUSION

The method offered for determining the boundaries of the acetabular walls is theoretically substantiated and has no analogues in the world. The technique is difficult to use in routine diagnosis of post-traumatic deformities of the acetabulum as it is complex and specialized software to be employed. However, the technique may be practical for preoperative planning of challenging cases of primary THR and for scientific analysis of surgical outcomes. The technique is very important for accurate preoperative planning of primary THR in the presence of severe post-traumatic deformities of the acetabular walls, for the selection of the acetabular component and additional constructs for the reliable fixation. Therefore, the results of primary THR can be improved with the technique used for patients with stage 3 post-traumatic hip arthritis.

Conflict of interest *None of the authors has any potential conflict of interest..*

Funding: *No additional funds were used.*

Ethical Approval *Not required.*

Informed Consent *Not required.*

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The article was submitted 06.09.2024; approved after reviewing 25.08.2025; accepted for publication 14.10.2025.

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