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Research Article

New concept in surgical anatomy of the acetabulum in the framework of hip arthroplasty. Fundamental study

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Abstract

The term “acetabular walls” appears both in publications analyzing the survival of endoprostheses and in various classifications developed within total hip replacement. Despite the accumulated experience, there is no information in publications on determining the boundaries of acetabular walls. Currently, an original classification of post-traumatic deformities of the acetabulum “ASPID” has been developed, which also does not describe the boundaries of the walls. Purpose of the study: to develop a method for determining the boundaries of acetabular walls in primary total hip replacement.

Materials and methods

Data from computed tomography of the pelvic bones of children aged 10-12 years and 30 preparations of the pelvic bones of adults without signs of acetabular dysplasia were used. Results. When analyzing 3D models of computed tomograms of the pelvic bones of children 10-12 years old without signs of acetabular dysplasia, extra-acetabular fixed anatomical landmarks were identified through which planes can be drawn dividing the children's acetabulum into conditional walls separated by cartilage. Then, the pelvic bones of 30 adults were scanned and similar structures were made, which made it possible to draw the boundaries of the walls of the acetabulum. The third stage was to determine the proportional ratio and area of each wall of the acetabulum in groups of children and adults and compare the results obtained. The absence of statistical differences in the groups of children and adults when determining the lobes of the superior, posterior and medial walls of the acetabulum indicates the high reliability of this technique.

Conclusion

The proposed technique allows, within total hip arthroplasty, to divide the acetabulum into the walls, which in some cases can make it possible to more accurately determine surgical tactics and improve the result of this surgical procedure, including within the framework of the original ASPID assessment system. The study is devoted to the theoretical aspects of total hip replacement.

Keywords: acetabulum; endoprosthetics; post-traumatic deformity; walls; ASPID

Introduction

Total hip replacement is the gold standard for treating hip pathology. Present total hip replacement began in the sixties of the last century [1]. Since then, numerous articles analyzing the outcomes, including long-term outcomes, and complications of this surgical procedure have been published around the world. The condition of the bone stock for implantation is one of the main factors in the reliability of primary fixation and survival of the artificial joint. To describe the surgical technique of the operation itself, analyze long-term results, complications and classify cases of primary and revision hip endoprosthetics, the concept of “acetabular walls” was introduced. Despite the more than fifty-year history of total hip arthroplasty, there is no definition of the concept of the boundaries of the “acetabular walls” in the literature. This definition relates to a greater extent to the theoretical aspects of endoprosthetics, however, at present, when using the term “acetabular walls", there is no clarification regarding their boundaries. The term "acetabular walls" is found both in publications on the analysis of the survival of endoprostheses, and in various classifications developed as part of total hip replacement [2-6]. Despite the accumulated experience in total hip replacement, there is no information on determining the boundaries of the acetabular walls, while, for example,[7] in the publication "Morphology of the bone structures of the acetabulum and the femoral component of the hip joint" describe in sufficient detail the parameters of the acetabulum, including the thickness of the walls, without specifying the boundaries of the latter [7]. Returning to classical orthopedics, in the classification of acetabular fractures AO, in addition to the columns, there are also damages of acetabular posterior wall, however, the boundaries of the walls are also not defined within the framework of the proposed fracture assessment system [8]. In addition, there is a Russian Federation patent dated December 28, 2020 "Method for choosing surgical tactics depending on the degree of deformation of the acetabulum and the state of the integrity of the pelvic ring in patients with post-traumatic coxarthrosis," in which the authors propose an original classification of post-traumatic deformities of the acetabulum "ASPID" based on three criteria, including localization of deformity: anterior, superior, posterior and medial walls of the acetabulum, In it authors also do not disclose a method for determining the boundaries of the walls listed above[9-10]. Thus, there is currently no described method for determining the boundaries of the acetabular walls, and where these boundaries lie within the framework of total hip arthroplasty, however, the concept of the "acetabular walls" has existed and has been widely used for a long period of time. The present study is devoted to solving this problem.

Purpose of the study: to develop a method for determining the boundaries of acetabular walls as part of primary total hip replacement.

Materials and methods of research

In the study, we used data from computed tomography of the pelvic bones of children aged 10-12 years and 30 preparations of the pelvic bones of adults without signs of acetabular dysplasia. Standard computer programs were used to construct 3D models and analyze them, determining the necessary landmarks, constructing planes, and dividing the acetabulum into walls. Computed tomograms of the pelvic bones of children aged 10-12 years without signs of hip dysplasia were taken as the theoretical basis for developing a method for determining the boundaries of the walls of the acetabulum for the following reason. It is known that at birth in children, the acetabular cartilaginous complex is located between the ilium above, the ischium below and the pubis in front. The outer two-thirds of this structure forms the so-called acetabular cartilage, and its medial third belongs to the medial wall. During puberty (10-12 years), the depth of the acetabulum increases due to the development of three secondary ossification centers. The "acetabular bone" is the secondary epiphysis of the pubis and contributes to the development of the anterior wall of the acetabulum. The acetabular epiphysis is the secondary growth center of the ilium and forms the main part of the superior wall of the acetabulum. The ischium also contains a small, innominate secondary growth center that helps form the posterior wall of the acetabulum [11-12].Thus, at the age of 10-12 years in children, the walls of the acetabulum are formed from 4 ossification centers (1 primary and 3 secondary). Since the final formation of the walls has not yet occurred at this age, a clear boundary between them is visible on computer tomograms. This phenomenon leads to this (research) effort to determine and describe the boundaries of the walls of the acetabulum using extra-acetabular landmarks. Landmarks must be determined established so that the lines drawn through them in the process of 3D modeling based on computed tomograms in adults are close to the lines of incomplete osteogenesis separating the walls of the acetabulum in children (Figure. 1).

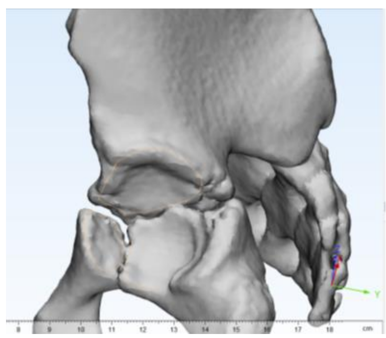

Figure 1: An example of a 3D model of the pelvis of a child aged 10-12 years.

Results

The first stage of the study was an analysis of computed tomograms of the pelvic bones of children 10-12 years old without signs of acetabular dysplasia. 3D models of the pelvic bones were constructed and extra-acetabular fixed anatomical landmarks were determined through which planes can be drawn dividing the children's acetabulum into conditional walls separated by cartilage. The second stage involved scanning the pelvic bones of 30 adults and carrying out similar constructions, which ultimately make it possible to draw the boundaries of the walls of the acetabulum. The third stage was the determination of the proportional ratio and area of each wall of the acetabulum in groups of children and adults, comparison of the results obtained to identify errors in measurements, followed by a conclusion about the possible consistency of the proposed method. At the first stage of the study, extra-acetabular landmarks were identified during the analysis of 3D models of the pelvic bones of children aged 10-12 years without signs of acetabular dysplasia, which formed the basis for the second stage of the study - the analysis of computed tomograms of the pelvic bones in adults. For this purpose, computed tomography of the pelvic bones was performed, on the basis of which a highly accurate three-dimensional surface of the pelvic bones was formed, on which the points designated at the first stage of the study were marked, namely: the most protruding point of the tubercle of the pubic bone [1], the most protruding point on the crest of the pubic bone [2], the most prominent point of the ischial tuberosity [3] and the most prominent point of the anterior inferior iliac spine [4]. The exit plane of the acetabulum is formed: the two most prominent points of the acetabular notch [5, 6] and a point on the upper wall of the acetabulum [7], obtained by drawing a perpendicular from the middle of the line of the transverse ligament to the upper wall. Next, the center point of the acetabulum is determined on the plane of its exit - the maximum transverse diameter was determined and the distance was divided in half. Further construction of the planes was carried out relative to the exit plane of the acetabulum and the point - the center of the acetabulum [8] (Fig. 2).

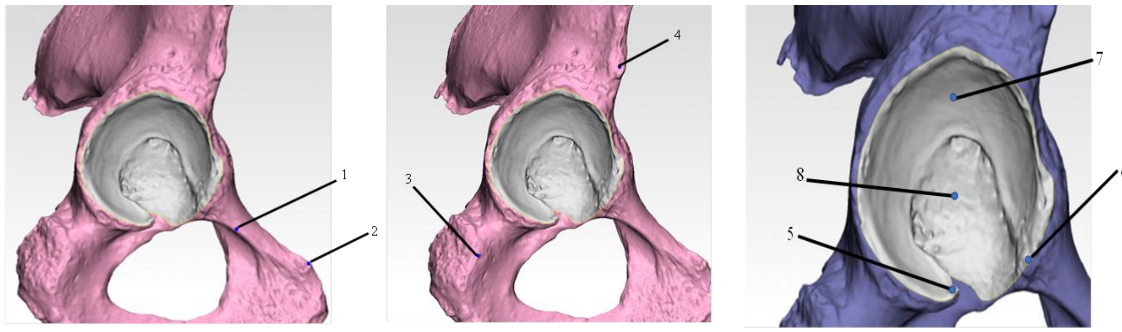

Figure 2: Marking points on the 3D model of the acetabulum.

The construction of planes was carried out using points both located directly on the triangular mesh of the computer model and freely located in a three-dimensional coordinate system. To construct the planes, we used 3D modeling applications with reverse engineering functionality. Three points are the minimum necessary and sufficient number to construct a plane in a three-dimensional coordinate system. The projection of a circle onto the wall of the acetabulum is constructed using the function of a planar drawing, the projection of the lines of which is superimposed on the surface of the triangulation model at the required angle. Definition of the boundaries of the acetabulum was performed using a tool for dividing the main mesh into separate surfaces, specifying a series of points that were subsequently connected into one closed line.The first plane is formed by points - the center of the acetabulum, the most protruding point of the tubercle of the pubic bone, the most protruding point on the crest of the pubic bone. The second plane is formed by points - the center of the acetabulum, the most protruding point of the ischial tuberosity and the most protruding point of the anterior inferior iliac spine.From the center point of the acetabulum, parallel to the plane of its exit, a circle is formed with a radius of ¼ of the maximum transverse diameter, thus projecting the medial wall. From the center point of the acetabulum, a perpendicular is lowered onto the projection of the transverse ligament parallel to the plane of exit of the acetabulum. Using an additional third point - the center of the medial wall, we obtain a plane that divides the fragment of the lower part of the acetabulum into the anterior and posterior sections (Fig. 3), which finally allows us to form the anterior, posterior, superior and medial walls (Figure. 4).

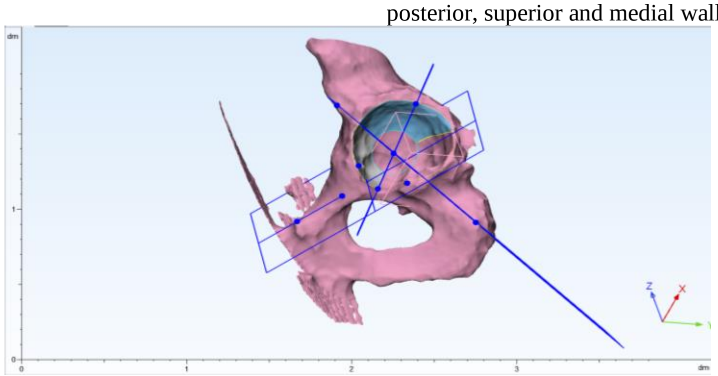

Figure 3: Division of the acetabulum using planes.

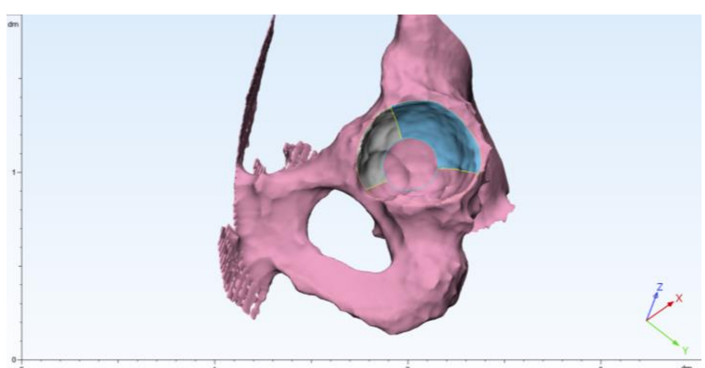

Figure 4: The acetabulum, divided into anterior, superior, posterior and medial walls after analyzing the 3D model of the pelvis.

Using the algorithm presented above, constructions were made on models of the pelvic bones of five children and 30 models of pelvic bones obtained by scanning anatomical preparations with a 3D scanner. At the third stage of the study, after modeling and dividing 35 3D models of the pelvis into walls, the areas and proportions of each wall were calculated in all cases. The results were entered into the appropriate tables to compare the data obtained in order to determine the consistency of the original method of dividing the acetabulum into “walls” presented in the publication as part of hip replacement. For this purpose, several statistical analysis methods were used. First, a one-way analysis of variance was carried out, as a result of which it was revealed that the ratio of percentages for the upper, posterior and medial walls of both adults and children does not differ statistically, which indicates the consistency of the developed methodology (Table 1). The indicators for the anterior wall differ slightly, but this may be due to the small number of measurements in the studied samples.

	A(%)	S(%)	P(%)	I(%)
Adults (30)				
Average value	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)				
Average value	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
Ratio of difference to difference error	2,93	0,72	1,27	0,33

Table 1. One-way analysis of variance (comparison of means of two samples).

The data from the last row (the ratio of the difference to the error of the difference) is compared with the tabulated value of the Student distribution at the 0.05 significance level with 30 + 5 – 3 = 32 degrees of freedom, which is 2.037. If the resulting number is greater than the table one (2.037), then it is considered that the data in the two samples differ - like at wall "A". In the remaining three cases - S, P, I - the obtained numbers are less than 2.037, and the data in the samples of adults and children do not differ. A similar result is obtained when using a nonparametric estimation method - the Mann-Whitney rank test (U-test, Wilcoxon-Mann-Whitney test), which allows you to test the hypothesis about the difference between two samples. The samples compared the percentages of each acetabular wall separately (Table 2). For each percentage share (A, S, P, I), data from both samples were combined and ordered (ranked) in ascending order. Each subject was assigned a serial number ("rank"). Then, separately for adults and children, the sums of ranks (R1 for the group of adults and R2 for the group of children) and U-statistics U1 and U2 were calculated using 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 n1 and n2 are the number of adults and children examined, respectively.

	A(%)	S(%)	P(%)	I(%)
Adults (n1 = 30 measurements)				
Sum of ranks R_1	483	561	569	542
U_1	132	54	46	73
Children (n2 = 5 measurements)				
Sum of ranks R_2	147	69	61	88
U_2	18	96	104	77
Table value of Mann-Whitney statistics at a confidence level of 0.05	39			

Table 2: The Mann-Whitney rank test.

The smallest of the two obtained numbers Ue = min (U1, U2) was chosen as the Mann-Whitney U-statistics. If the value of the Mann-Whitney statistic Ue was less than the table value (for example, when measuring the percentage of wall "A"), the null hypothesis of no differences between the two samples was rejected and the alternative hypothesis was accepted, that is, the difference between the two samples was considered statistically significant. In the remaining three cases - for the percentages of walls S, P, I - the data in the samples of adults and children do not differ. However, from the interval diagram below you can see that the difference in the percentages of wall A in adults and children is also not very significant (there is no difference in walls S, P, I) (Figure. 5).

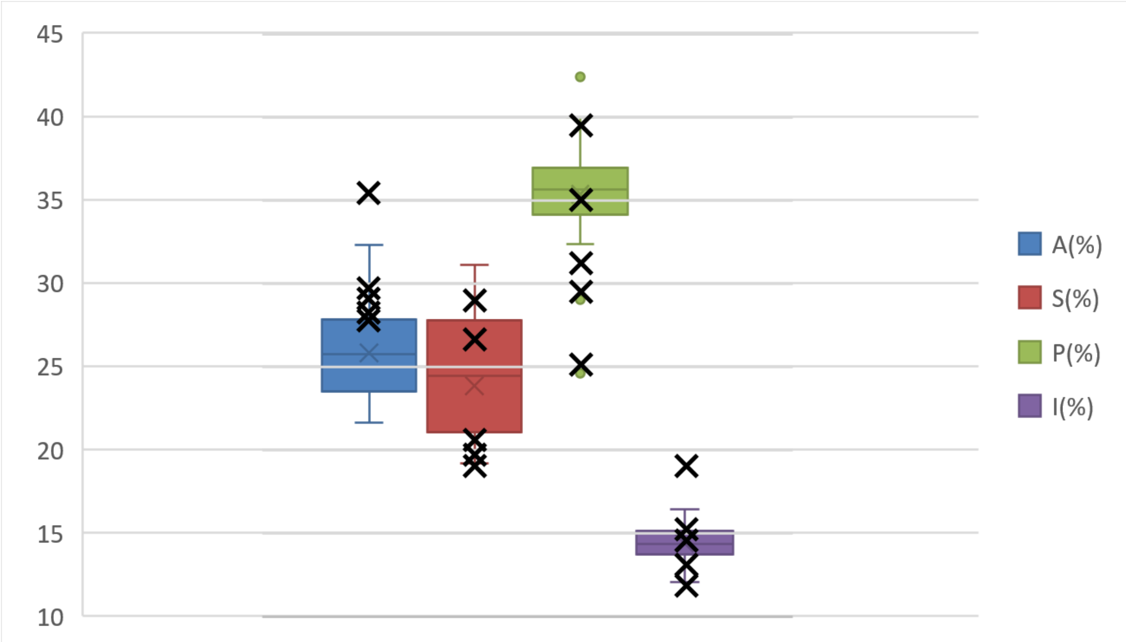

Figure 5: Interval diagram (difference in the percentages of walls in adults and children).

Here, the colored elements refer to data in adults, and the black oblique crosses refer to the corresponding data in children. Filled rectangles correspond to the second and third quartiles, horizontal lines in the middle of these rectangles are medians, T-shaped extension lines ("whiskers") indicate maxima and minima without taking into account outliers, individual colored dots (only at "P" in the diagram) –outliers, that is, values deviating from the main sample by more than 1.5 interquartile ranges from the nearest quartile.

Conclusions

1. The proposed method for determining the boundaries of the walls of the acetabulum is currently the only one in the world literature that is theoretically credible.

2. Statistical differences between the group of children and adults in determining the proportion of the anterior wall of the acetabulum are insignificant and are likely due to the small number of measurements in the groups. The absence of statistical differences in the groups of children and adults when determining the lobes of the superior, posterior and medial walls of the acetabulum indicates the high reliability of this technique.

3. To further assess the reliability of this technique, a larger number of measurements performed by several specialists with the determination of Cohen's Kappa coefficient and statistical analysis of the results are required.

4. The proposed technique allows, within the framework of the ASPID classification, to more accurately determine the boundaries of the walls of the acetabulum, which will certainly help improve the results of primary hip replacement in patients with stage 3 post-traumatic coxarthrosis through a more accurate choice of surgical tactics depending on the localization of the deformation of the walls.

Discussion

Analysis of the literature on various aspects of hip replacement shows frequent confusion among researchers on what should be considered the "acetabulum walls". Due to the fact that such a concept does not exist in human anatomy, novice surgeons may encounter various misconceptions, along with inconsistencies on how to perform hip replacement techniques such as implanting the acetabular component of the prostheses. This may not be a problem during standard primary arthroplasty when damages to the acetabulum are limited to minor changes without consequences of any fractures or congenital pathology, and the bone base does not have structural changes or deformation. In contrast to the above, in the presence of injuries of traumatic origin, the anatomy of the acetabulum acquires its own unique configuration, which is difficult to describe and classify due to the absence of a generally accepted assessment system. As a result, publications on the results of arthroplasty in patients with consequences of acetabular fractures are scattered, cover extremely small groups of patients, and have no global practical value due to the lack of a generally accepted systematic approach. In Russian Scientific Research Institute of Traumatology and Orthopedics named after R.R. Vreden has developed an original typing system to describe the acetabulum in the sequel after the fracture, which is called "ASPID" by analogy with the TNM system, which has found its use in oncology. Since the basis of the proposed "ASPID" system are acetabular walls, the concept of the boundaries of the latter is necessary, including in relation to theoretical aspects that confirm the need to implement this original system. In conclusion, the presented study is unique, as it has no analogues, and could be a templet for a larger scale study focused on analysis of the condition of acetabulum in patients with various congenital and post-traumatic deformities.

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