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ACETABULAR MORPHOMETRY DURING DEVELOPMENTAL DYSPLASIA OF THE HIP: IMPLICATIONS FOR TOTAL HIP REPLACEMENT

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Annotation. *The article addresses the issue of diagnosing of acetabular dysplasia in terms of total hip replacement needs. There were outlined a group of roentgen-morphometric parameters that integratively describe acetabular morphology implicated to the cup implantation and defined their normal values via MSCT-investigation of 60 intact hips. New approach for assessment of acetabular medial wall bone stock in cup implantation site was proposed.*

Key words: *total hip replacement, developmental dysplasia of the hip, acetabulum, morphometry, CT.*

Introduction. Total hip replacement (THR) during developmental dysplasia of the hip (DDH) remains to be challenging surgical procedure due to demanding operative technique and high risk of intra- and postoperative complications connected with acetabular component instability [7, 15, 17-20]. Acetabular reconstruction remains to be one of the crucial aspects of THR during DDH that provides endoprosthesis' long-term stability and general success of the operation.

It implies acetabular component implantation at the level of the true acetabulum, restoration of adequate bony coverage and spatial reorientation of the cup that often requires aggressive surgical manipulations to be performed [8, 18, 19, 35]. Successfulness of aforementioned manipulations strongly depends on precise assessment of bony morphology of the acetabular implantation site in order to provide implant's primary and delayed stability and to prevent dangerous neurovascular complications [3, 9, 35].

Thus there is a need to outline a group of roentgen-morphometric parameters that are able to integratively describe acetabular morphology implicated to the endoprosthesis implantation. Such parameters should be taken into consideration and form the base of precise individual preoperative planning of THR during DDH.

According to the authors [5, 14, 27, 32], routine radiography remains to be only a screening diagnostic tool allows to detect rough anatomical abnormalities and doesn't satisfy the demands for precise implantation preplanning thus requiring extended diagnostic program including tree-dimensional visualization methods. Moreover, large amount of scientific research data based on the routine biplane radiography is considered to be biased due to errors of patient positioning, X-ray image overlapping and projected image measurements [5, 14, 34]. Thus implementation of modern tree-dimensional diagnostic tools for visualization such as MDCT allows to detect variable morphological abnormalities of the acetabulum during DDH thus demonstrating an outstanding value for operative surgeon [5, 14, 33].

Thus, considering the demands of acetabular component implantation technique during DDH it's worthwhile to include in the group such roengen-morphometric parameters, that describe:

- sphericity;
- sectoral bony coverage;
- spatial orientation (version) of the acetabulum;
- bone stock in the implantation site.

Researchers are of similar opinion that verification of complicated and occulted morphological abnormalities during DDH requires reliable visualization tools for three-dimensional assessment of acetabular sectoral coverage [1, 2, 5, 14]. Notably, that "classic" dysplastic lack of bony coverage of the upper acetabular wall can be firmly detected through the assessment of lateral centre-edge angle (LCE-angle, Wiberg's angle) and acetabular horizontal inclination angle (Sharp's angle) on standard two-dimensional X-ray [5, 14, 30, 31]. But application of biplanar radiometric indices, such as «crossover sign» or «posterior wall sign» for verification of anterior and posterior acetabular wall deficiency can't be justified due to low diagnostic value [14, 32].

Approach for verification of acetabular sectoral coverage conducted by Anda S. et al., 1986 [1], implies assessment of anterior acetabular sector angle (AASA), posterior acetabular sector angle (PASA) and horizontal acetabular sector angle ((HASA) based on MSCT-measurements along with routine Wiberg's and Sharp's angles representing upper acetabular wall coverage (Fig.1).

Normative values of some of the aforementioned sectoral angles were set at the level of: AASA ≥ 50◦, PASA ≥ 90◦, HASA ≥ 140◦ through multicentre research during the past decades [1,2, 11, 16, 28].

In the opinion of Xenakis et al. [32] and Mendes D.G. et al. [23] localization and the degree of acetabular wall deficiency as well as version of the acetabulum are the key points for the implantation technique decision-making. Previous studies suggested suboptimal correction of abnormal acetabular version and coverage can result in inferior clinical results [7, 15, 19, 35]. Although the majority of patients with DDH present with excessive anterversion, previous studies have shown the acetabular version and the quantity and location of acetabular deficiencies can vary among individuals [12, 13, 25, 33]. Thus, when planning THRs, it is important to assess the morphologic features of the hip of each patient three-dimensionally and to customize the correction in accordance with this individual variation [18, 25, 32, 33]. It's noteworthy that assessment of acetabular version through the routine X-ray measurements seems to be biased due to low specificity of «crossover sign», proposed earlier for the detection of acetabular retroversion. [12, 34].

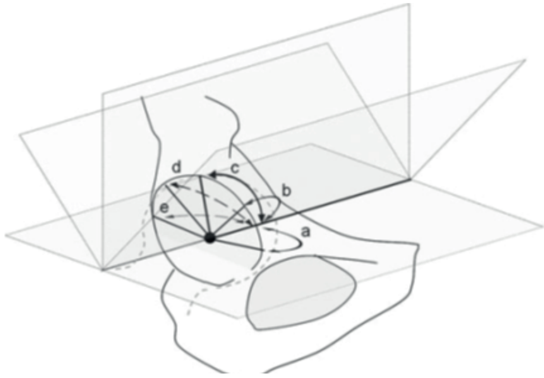


Fig. 1. Stratification scheme of acetabular wall coverage according to acetabular sectors:
a - anterior sector; b - antero-superior sector; c - superior sector; d - postero-superior sector, e - posterior sector.

Among the parameters that influence surgical technique of acetabular reconstruction, medial wall bone stock in the site of endoprosthesis' bed zone should be taken into special consideration [19, 20, 22]. But the majority of articles dedicated to the issue are focused only on the acetabular medial wall thickness at the level of the lig. teres bed. Only several descriptive cadaveric studies elucidate the morphology of the acetabulum at the cup implantation site [24, 29]. Thus there's a need to elaborate clear methodology for assessment of bone stock at the implantation site through reliable diagnostic tools as part of operative technique decision-making.

Research purpose. To outline a group of roentgen-morphometric parameters that are able to integratively describe acetabular morphology implicated to the acetabular component implantation during DDH and to determine normal values of the parameters via MSCT-investigation.

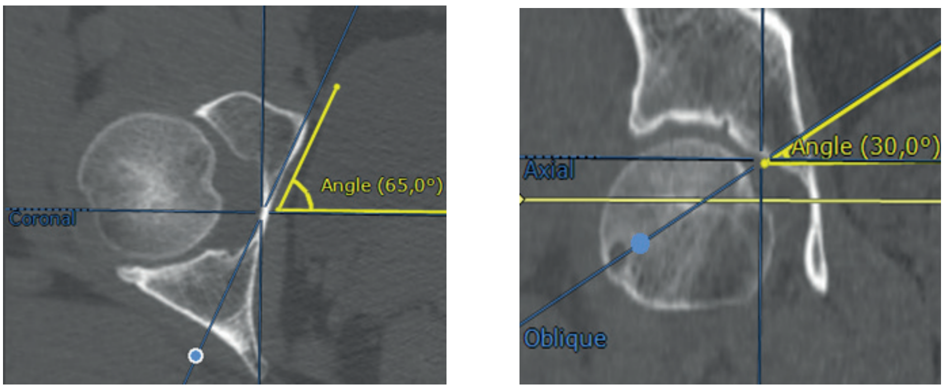
Research methodology. We prospectively reviewed pelvic CT scans from 35 patients (70 hips) with no history of hip disease, obtained during their preoperative examinations for a non-orthopaedic reasons between September 2018 and February 2020. There were 12 male (34,3%) and 23 female (65,7%). The average age of the patients at examination was 52 years (with 95% CI [49; 55], range, 22–65 years).

Pelvic CT was performed with patients in a supine position using "Pelvis" study protocol (kV 130; б) sec/mAs: 3,1 / 217; slice [mm] 0,625; tube position (anterior); length [mm] 256; algorithm [standard]). The images were obtained at 0,625-mm intervals from the anterior superior iliac spines to the inferior rim of the pelvis. Only the studies with clear visualisation of all morphological structures of acetabulum were included for the following research.

In accordance to the aim of the work morphometric measurements of acetabular indices were performed on a multiplanar reconstructed CT-scans of the pelvis using image processing software (Myrian 2.0; Intrasense, Montpellier, France). Assessment of acetabular sphericity parametres included (Acetabular frontal sphericity index (ASIf); acetabular horisontal sphericity index (ASIh), acetabular sphericity angle (ASpA). Acetabular sphericity indices were obtained as the ratio of acetabular depth to its width in frontal and horizontal axes, respectively (Fig. 3A-B) [1, 2, 27].

Acetabular coverage of the femoral head was evaluated by measuring the acetabular sector angle (ASA) in three directions, based on the method described by Anda et al., 1991 [2] and implied: anterior acetabular sector angle (AASA), posterior acetabular sector angle (PASA), horizontal acetabular sector angle (HASA) (Fig. 4A-B), lateral centre-edge angle (LCEA, Wiberg's angle) and acetabular horizontal inclination angle (Sharp's angle). Regarding spatial orientation (version) of the acetabulum, we measured the acetabular anterversion angle on the axial plane passing through the center of the femoral head (Fig. 5A) The cranial anterversion angle [2, 11, 12, 16] was measured on the axial plane 5 mm distal to the acetabular roof to determine the existence of acetabular retroversion or excessive anterversion (Fig.5a).

Evaluation of the acetabular medial wall bone stock was performed within two locations: in site of the lig.teres bed and in the projection of the top of the cup reamer (cup implantation site). These parameters were assesed by designed methodic [24] which implies reformation of horizontal CT-image at the level of the centre of acetabulum through 65º-inclination to the sagittal axis which corresponds to the axis of biomechanical centre of the hip (Fig.2a) [4, 6, 19].



a b

Fig. 2. Stages of CT-image reconstruction while obtaining topogram for assessment of the acetabular medial wall width: *a – horizontal CT-image at the level of the centre of acetabulum; б – reformed image with 65º-inclination to the sagittal axis.*

Further reconstruction required 30º-inclination of obtained scan (Fig.2b) to the frontal axis which corresponds to the desirable direction of the cup reamer during the insertion. The medial wall width measurements were performed at the level of the lig. teres bed and 10 mm cranially, which corresponds to the top of the cup reamer (Fig.2b) [27].

Data are presented as median with 95% confidence interval. Eighty percent of the data were abnormally distributed using the Shapiro-Wilk test. Therefore a non-parametric approach was chosen for analysis. Non-parametric analysis of variance (non-parametric ANOVA) on each dependent variable, with one within-subject factor (side) on two levels (right and left side), and one between-subject factor (gender) on two levels (male and female) and Mann-Whitney test were used. When possible the exact p level, the mean difference, and its confidence interval (95%) were given. Correlations between two continuous parameters were evaluated using Spearman's rank correlation coefficient. Statistical tests were carried out with Statistica (version 8.0, Statsoft).

Results.

Table 1

Values of the acetabular roentgen-morphometric parameters of th e group comparable with literature data

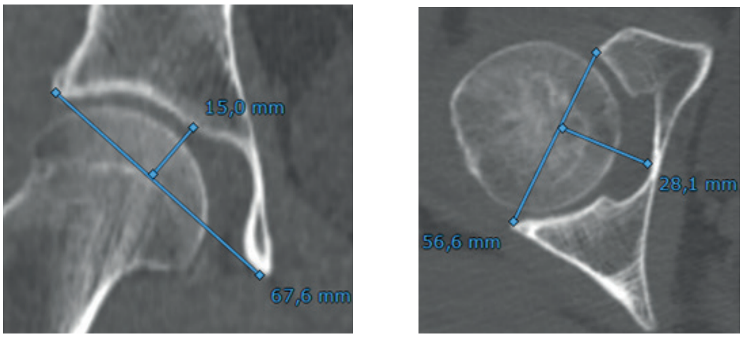
Roentgen-morphometric parameters	Parameter's value	
	Research data	Literature data
Acetabular frontal sphericity index (ASIf)	0,48 (95% CI, 0,46-0,51)	**
Acetabular horizontal sphericity index (ASIh)	0,48 (95% CI, 0,46-0,51)	0,45
Acetabular sphericity angle (ASpA)	89º (95% CI, 84º-92º)	**
Anterior acetabular sector angle (AASA)	63,5º (95% CI, 57º-68º)	≥ 50º
Posterior acetabular sector angle (PASA)	105º (95% CI, 97º-115º)	≥ 90º
Horizontal acetabular sector angle (HASA)	166º (95% CI, 163º-178º)	≥ 140º
Lateral centre-edge angle (LCEA)	40º (95% CI, 39º-43º)	≥ 25º
Acetabular horizontal inclination angle (Sharp's angle)	37º (95% CI, 35º-38º)	≤ 40º,
Acetabular anteversion (AcetAV-angle)	22◦ (95% CI, 17º-26º)	17-22º
Acetabular medial wall width (in projection of lig. teres bed)	4,3 mm (95% CI, 3,3-4,8)	*
Acetabular medial wall width (in projection of cup implantation site)	7,2 mm (95% CI, 6,2-7,8)	**

** - normative value is still under discussion; ** - normative value is not presented in the literature.*

Analysis of the roentgen-morphometric data of the group allowed to obtain the following normative values of the parameters:

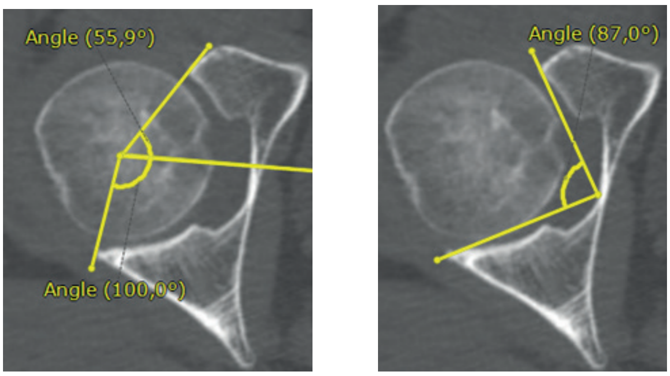
- acetabular sphericity: ASIf - 0,48 (95% CI, 0,46-0,51), ASIh - 0,48 (95% CI, 0,46-0,51), acetabular sphericity angle - 89º (95% CI, 84º-92º);
- acetabular sectoral coverage: ASA - 63,5º (95% CI, 57º-68º), PASA - 105º (95% CI, 97º-115º), HASA - 166º (95% CI, 163º-178º), LCEA - 40º (95% CI, 39º-43º), acetabular horizontal inclination angle (Sharp's angle) - 37º (95% CI, 35º-38º);
- spatial acetabular orientation: acetabular anterversion angle - 22◦ (95% CI, 17º- 26º);
- acetabular medial wall bone stock: acetabular medial wall width (in projection of lig. teres bed) - 4,3 mm (95% CI, 3,3-4,8), acetabular medial wall width (in projection of cup implantation site) - 7,2 mm (95% CI, 6,2-7,8).

Notably that most of the obtained results are in accordance with literature data [1, 2, 11, 16, 27, 30, 31], meanwhile rest are still under discussion (table 1).



a b

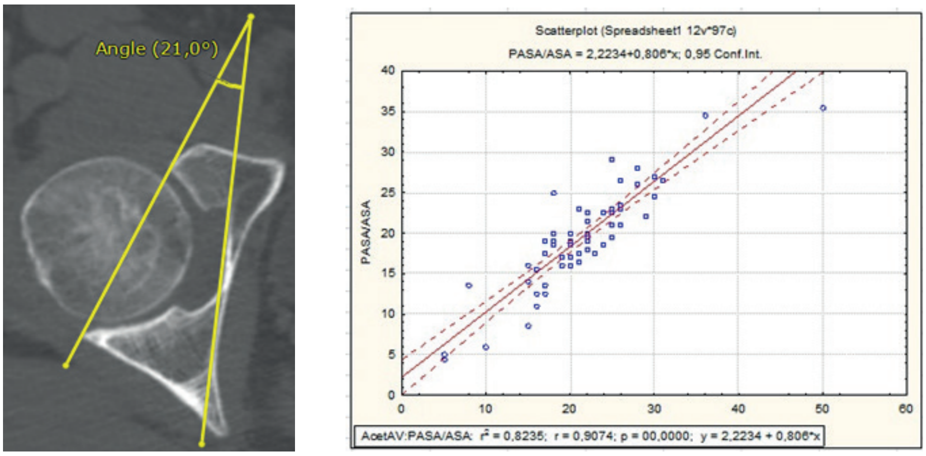
Fig. 3. CT image of the pelvis showing measurement of: *a – acetabular frontal sphericity index (ASIf); б – acetabular horizontal sphericity index (ASIh);.*



a b

Fig. 4. CT image of the pelvis showing measurement of: *a – acetabular sectoral coverage angles (AASA, PASA, HASA); б – acetabular sphericity angle (ASpA).*

Acetabular anterversion was measured on horizontal CT-image as the acute angle between the acetabular opening plane and the sagittal plane of the pelvis, at the widest level of the acetabulum; a negative value indicates retroversion (Fig.5a). The mean group value was defined as 22◦ (95% CI, 17º-26º) that corresponds to the literature data presented at the level of 17-20º [11, 16, 27]. There were defined no statistical differences in acetabular anterversion between age and gender subgroups (p>0,9).



a b

Fig. 5: *a - CT image of the pelvis showing measurement of acetabular anterversion angle (AcetAV-angle); b - scatterplot showing correlation of acetabular anterversion with ratio: (PASA-AASA)/2, (r= 0,9, p<0,00001)*

However there were defined strong correlation (r=0,9, p<0,00001; pic.4b) of acetabular anterversion with ration of anterior and posterior acetabular sector angles, that can be described as:

½ x (PASA-AASA).

Such a regularity gives an evidence of strong relation of anterior and posterior wall coverage with spatial orientation of acetabulum that should be addressed to embryo-morphological development of the pelvis and its individual peculiarities.

Thus anterversion as a single parameter doesn't reflect all the complexity of acetabular morphology and should be taken into consideration together with other coverage indices during preoperative planning.

There were revealed that measurements in site of the crucial ligament's bony bed based on pelvic images obtained by conventional biplanar X-ray remains to be biased and doesn't correspond true acetabular medial wall bone width. Absolute width of the acetabular medial wall at the sites of the lig. teres / acetabular component's bony beds carried out through special MSCT-recontruction methodic was defined as: 4,3 mm (95% CI, 3,3-4,8) / 7,2 mm (95% CI, 6,2-7,8) for normal hips.

The mean error between conventional biplane X-ray and MSCT measurements of medial wall width at the site of lig. teres bed was defined as 1,6 mm (95% CI, 1,4-1,8). Such a measurement distortion due to X-ray irregular magnification and superimposition should be taken into consideration and requires detailed preoperative MSCT-visualization.

Discussion. Without a doubt, the reconstruction of the acetabulum and implantation of the acetabular component is the key and, at the same time, the most technically demanding aspect THR during DDH in providing the success of operation [7,8, 15, 17-20, 25]. Since the implantation of the cup above or laterally to the level of the hip biomechanical center is considered to be a risk factor for the development of instability of acetabular and femoral components [3, 8, 9] its implantation in the projection of the true bed of the acetabulum seems to be crucial [8, 19, 20, 25], which, in turn, is associated with the difficulties of orientation and acetabular component and its incomplete bony coverage [8, 11, 15, 25, 35].

Preoperative verification of the diagnosis and operative technique determining during DDH requires a thorough evaluation of variative morphologic alterations of acetabulum, using reliable methods of spatial visualization. According to researchers, routine X-rays during DDH should be considered only screening method [2, 5, 14, 18, 30, 31]. So, "classic" diagnostic criteria for dysplasia evaluated on radiographs, are of considerably inferior sensitivity while assessing acetabular sectoral coverage, spatial orientation and cup implantation site. [14, 32]. Thus, the reconstruction of the acetabulum requires a reliable three-dimensional diagnostic of its morphologic alterations. Previous studies have described numerous morphologic alterations in DDH and the existence of individual variation resulting in deformities [5, 13, 25, 32,33].

The only criteria of acetabular sectoral deficiency that can be reliably detected by radiography, are the Wiberg's and Sharp's angles, reflecting the lack of superior wall cover. However, lack of coverage of superior wall is the most stable and is detected in all cases of DDH, meanwhile the lack of anterior and posterior walls and frontal inclination (version) are characterized with significant variability and are available for evaluation only during precise CT-morphometry [1, 2, 5, 13, 25, 32].

Acetabular anterversion seems to be one of the crucial parametres in terms of cup implantation and the most controversial at the same time, cause its normal value varies a lot among the researchers. However, the authors are of similar opinion that this parameter is not of a great clinical value while assessed isolated because of its relative nature and is determination by the ratio of the anterior and posterior wall coverage of the acetabulum [2, 10-13, 16, 21]. Consequently, acetabular excessive anterversion may be due to the insufficient coverage of the anterior wall, or excessive coverage of the posterior one [25]. According to J. J. Nepple et al. [25] in 46% of cases of dysplasia the acetabular inclination angle is $\leq 15^o$, while, in 54% - is $\geq 15^o$. The same authors reported the incidence of cases of retroversion of acetabulum during DDH as 1:7. Notably, that there's a significant incidence of acetabular retroversion among the male population (80% of cases among men compared to 29% in females) [12], which however was not confirmed in the current work.

As mentioned above, the scientific search of the previous decades for the medial wall bone stock during dysplasia was focused only around its thickness at the level of lig. teres bed via a routine biplane radiography. And the presented results are in a rather disparate values: from 2 to 8 mm in norm and from 7 to 40 mm in terms of dysplasia [22, 24, 26, 29, 30]. It's noteworthy that the data regarding the thickness of the medial wall directly in the cup implantation site we managed to find only in a few articles, which are of anatomical and morphological nature and are based on the study of few human cadaver material [24, 29]. The data also were of descriptive nature and devoid of stratification that meets the needs of THR.

Conclusions. The conducted research allowed to outline the group of roentgen-morphometric parameters that holistically describes the morphology of the acetabulum implicated to the acetabular component implantation while performing THR during DDH. Based of the CT-morphometry of intact hip joints, there were defined the values of the parameters that should be considered as normative while diagnosing acetabular dysplasia. There were proposed methodology of a comprehensive assessment of cup implantation site during preoperative planning, allowing to choose the optimal surgical approach and to predict the risks of intra - and postoperative complications of THR during DDH. Undeniable is the clinical benefit of CT-morphometric evaluation of the acetabular morphology in terms of preoperative planning, such as allowing to verify the topography and quantitative characteristics of acetabular bone stock, which is considered to be the key in implantation technique selection.

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