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Variants of Acetabular Deformity in Developmental Dysplasia of the Hip in Young Children

Pavel I. Bortulev [1], Tamila V. Baskaeva [1], Sergei V. Vissarionov [1,2], Dmitriy B. Barsukov [1], Ivan Yu. Pozdnikin [1], Makhmud S. Poznovich [1]

[1] H. Turner National Medical Research Center for Children's Orthopedics and Trauma Surgery, St. Petersburg, Russia

[2] Mechnikov North-Western State Medical University, St. Petersburg, Russia

Background. The choice of pelvic reconstruction technique in children with developmental dysplasia of the hip (DDH) has been the subject of discussion for many years and is often determined by personal preferences of a surgeon rather than by X-ray anatomical state of the acetabulum. The variants of its anatomy structure have still not been reflected in the available scientific literature.
Aim of the study — to identify the most typical variants of acetabular deformation in children with varying severity of DDH, based on the X-ray anatomical analysis of structure of the acetabulum.
Methods. The study was based on the results of examination of 200 patients (200 hip joints) aged 2 to 4 years (3.1±0.45) with Tönnis grade II-IV DDH. All patients underwent conventional clinical and radiological examination. The latter consisted of hip radiography in several views and computed tomography. We took the values of acetabular index, the extent of acetabulum arch and the presence or the absence of bone oriel as criteria for determination of the most typical variants of acetabular deformation.
Results. X-ray analysis of anatomical structure of the acetabulum in young children with varying severity of DDH revealed 3 most common variants of acetabular deformity: 1 — moderate underdevelopment of the acetabulum arch (AI ≤ 35°), its shortening and the presence of bone oriel; 2 — pronounced underdevelopment of the acetabulum arch (AI > 35°), its shortening and the presence of bone oriel; 3 — pronounced underdevelopment of the acetabulum arch (AI > 35°), its sufficient length and the absence of bone oriel.
Conclusion. Suggested supplements to existing Tönnis DDH classification might become basic for choosing the surgical correction technique of the acetabulum in children with different severity of DDH.

Keywords: developmental dysplasia of the hip, DDH, children, acetabular deformity, pelvic osteotomy.

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Pavel I. Bortulev; pavel.bortulev@yandex.ru

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Варианты деформации вертлужной впадины при дисплазии тазобедренных суставов у детей младшего возраста

П.И. Бортулёв [1], Т.В. Баскаева [1], С.В. Виссарионов [1,2], Д.Б. Барсуков [1], И.Ю. Поздникин [1], М.С. Познович [1]

[1] *ФГБУ «Национальный медицинский исследовательский центр детской травматологии и ортопедии им. Г.И. Турнера» Минздрава России, г. Санкт-Петербург, Россия*

[2] *ФГБОУ ВО «Северо-Западный государственный медицинский университет им. И.И. Мечникова» Минздрава России, г. Санкт-Петербург, Россия*

Актуальность. Выбор методики реконструкции таза у детей с дисплазией тазобедренного сустава остается предметом дискуссий на протяжении многих лет и часто зависит от личных предпочтений хирурга, а не от рентгеноанатомического состояния вертлужной впадины, варианты строения которой не отражены в научной литературе.
Цель исследования — на основании рентгеноанатомического анализа строения вертлужной впадины выявить наиболее распространенные варианты ее деформации у детей с различной степенью тяжести дисплазии тазобедренных суставов.
Материал и методы. Исследование основано на результатах обследования 200 пациентов (200 тазобедренных суставов) в возрасте от 2 до 4 лет (3,10±0,45) с дисплазией тазобедренных суставов II–IV ст. по классификации D. Tönnis. Всем пациентам проводили клиническое и лучевое исследование по общепринятой методике. Лучевое исследование заключалось в выполнении рентгенографии тазобедренных суставов в нескольких проекциях и компьютерной томографии. В качестве критериев для определения наиболее типичных вариантов деформации вертлужной впадины нами были выбраны значения ацетабулярного индекса, величина протяженности свода вертлужной впадины и наличие или отсутствие костного эркера.
Результаты. Рентгенометрический анализ состояния вертлужной впадины у детей младшего возраста с различной степенью тяжести дисплазии тазобедренных суставов показал наличие трех наиболее часто встречающихся вариантов деформации вертлужной впадины: вариант 1 — умеренно выраженное недоразвитие свода вертлужной впадины (АИ≤35°), его укорочение и наличие костного эркера; вариант 2 — выраженное недоразвитие свода вертлужной впадины (АИ>35°), его укорочение и наличие костного эркера; вариант 3 — выраженное недоразвитие свода вертлужной впадины (АИ>35°), его достаточная протяженность и отсутствие костного эркера.
Заключение. Предложенные дополнения к имеющейся классификации дисплазии тазобедренных суставов, разработанной D. Tönnis, могут стать основой алгоритма выбора методики хирургической коррекции вертлужной впадины у детей с различной степенью тяжести дисплазии тазобедренного сустава.

Ключевые слова: дисплазия тазобедренного сустава, дети, деформация вертлужной впадины, остеотомия таза.

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Бортулёв Павел Игоревич; e-mail: pavel.bortulev@yandex.ru

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BACKGROUND

According to many authors, dysplasia of the hip is one of the most common pediatric orthopedic diseases with the incidence rate of 3-4 to 50 cases per 1000 newborns. A severe degree of hip dysplasia characterized by prominent anatomic changes developed ante- and postnatally still plays one of the leading roles among all congenital musculoskeletal disorders [1, 2, 3, 4].

Impossibility of ultrasonic screening examination, as well as its improper interpretation and indiscriminate application of conservative therapy methods force to perform surgical stabilization of the joint in order to restore correct relations between pelvic and femoral components during reconstructive surgeries. The Tönnis classification of hip dysplasia and its modification, the International Hip Dysplasia Institute (IHDI), are used to verify the disorders of intraarticular relations in the hip joint before starting the surgical treatment [5, 6]. Many Russian and foreign authors proved the efficacy of the surgeries on pelvic components, such as Salter innominate osteotomy of the pelvis, Pemberton pericapsular osteotomy, Dega's acetabuloplasty and combined Salter-Pemberton pelvic osteotomy, described by P.C. Perlik [7, 8, 9, 10, 11, 12, 13].

The choice of pelvic reconstruction technique has been the subject of discussion for many years and is often determined by the surgeon's qualification and experience, as well as his personal preference for one or another technique, rather than by the radiological and anatomical conditions of the acetabulum, whose structural variants have not been found in the available scientific literature. Besides, the available classifications of hip dysplasia reveal only the degree of femoral head dislocation. Said facts necessitate more detailed study of radiological and anatomical conditions of the acetabulum in order to identify its most typical deformities. In our opinion, these pathologic changes will determine the choice of the reconstruction technique of the acetabulum.

Aim of the study. Basing on the X-ray anatomy of the acetabulum, to identify the most frequent types of its deformity in children aged 2 to 4 years with varying severity of hip dysplasia.

METHODS

Study design: monocenter cohort retrospective.

Inclusion criteria:

– age 2-4 years;

– presence of Tönnis grade II-IV unilateral hip dysplasia [5];

– absence of any signs of dysplastic changes in the contralateral joint;

– absence of any prior surgeries on the pelvic component of the joint;

– no neurological diseases;

– no genetic or systemic skeleton diseases;

– consent of the patient's legal representatives to participate in the study.

Exclusion criteria:

– age under 2 years and over 4 years;

– presence of bilateral hip dysplasia;

– prior hip surgeries;

– neurological, systemic or genetic diseases;

– refusal to fill out the informed consent to participate in the study.

The study included 200 patients (200 hip joints) aged 2 to 4 years (3.10±0.45) with Tönnis grade II-IV hip dysplasia who were admitted to the hospital for the following surgical treatment between 2016 and 2021. All patients underwent the standard clinical examination typical for this orthopedic pathology, hip X-rays in AP and Lauenstein views, in position of abduction and internal rotation of the lower extremities, as well as computed tomography.

We selected the following criteria to determine the most common types of acetabular deformity:

– acetabular index (AI) — the angle formed by the line connecting both Y-shaped cartilages (Hilgenreiner line) and the tangent line to the acetabular arch;

– length of the acetabular arch — the distance from the inferomedial to its superolateral point (to the Ombredanne-Perkins line);

– bony prominence — the presence or absence of a step-like transition of the upper edge of the acetabulum into the iliac wing.

In order to objectify the data, the above-mentioned criteria were calculated using both X-rays and CT slice in the middle of the acetabulum (Figs. 1, 2).

Statistical analysis

Statistical analysis was performed using SPSS Statistic v.26 software (IBM, USA). Arithmetical mean (M), standard deviation (SD), median (Me) with quartiles (25-75%) were calculated. Within groups, the data obtained were analyzed using Wilcoxon criterion. Correlation analysis (Pearson criterion) was performed, and the strength of correlation was assessed as follows: $0.01 \le p \le 0.29$ — weak correlation; $0.30 \le p \le 0.69$ — moderate correlation; $0.70 \le p \le 1.00$ — strong correlation. The coefficient value determined the presence of a positive or negative correlation. Regression analysis in the form of paired linear and quadratic regression models was performed to assess the degree and the variant of the influence of one attribute on another. Sample proportion was estimated using the coefficient of multiple determination (R^2).

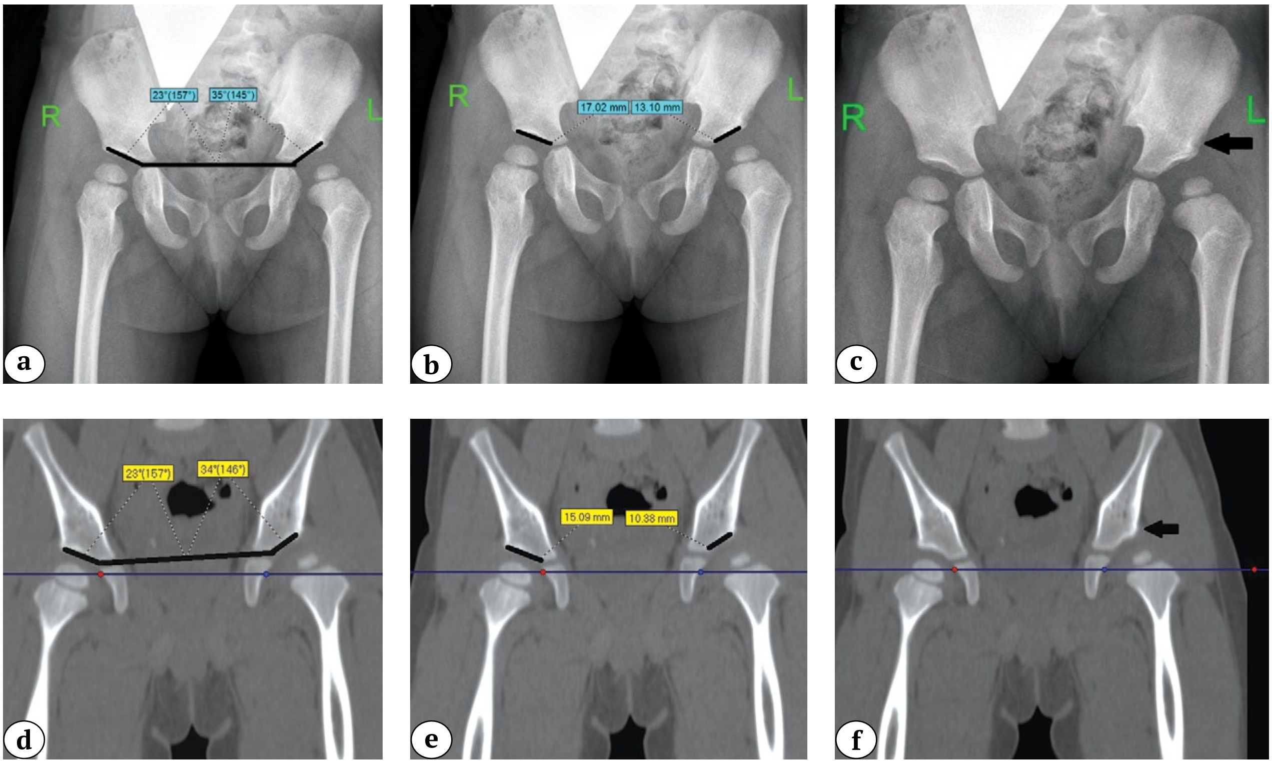

Fig. 1. Determination in patients with Tönnis grade II DDH based on X-ray and CT results:
a, d — acetabular index;
b, e — extent of acetabulum arch (length of the sclerosis zone);
c, f — presence of bone oriel (indicated by black arrow)

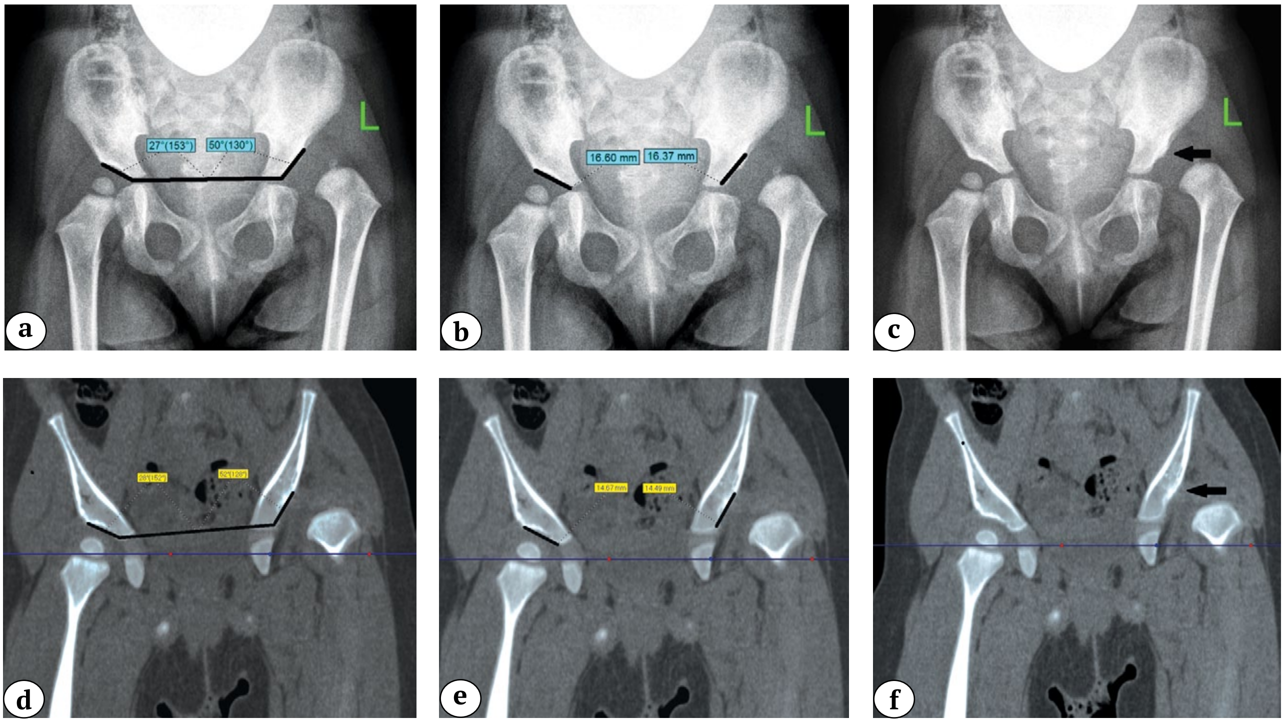

Fig. 2. Determination in patients with Tönnis grade IV DDH based on X-ray and CT results:
a, d — acetabular index; b, e — length of acetabulum arch;
c, f — absence of bone oriel (indicated by black arrow)

RESULTS

Legal representatives of the patients complained of lameness in children on admission to the hospital. The relative shortening of the lower extremity was 1.7±0.5 cm. Goniometry changes were typical for hip dysplasia in form of abduction restrictions and excessive rotational movements on the side of the lesion.

Results of performed radiometry according to the above-mentioned X-ray anatomy criteria of the acetabulum in patients with various severity of dysplasia are presented in Table 1.

Basing on the Table 1 data, it can be concluded that there was the marked underdevelopment and shortening of the acetabular arch in the overall cohort of patients. It should be noted that by shortening of the arch we mean a situation in which the difference in measurement compared to the contralateral joint is at least 25% of the individual norm. Moreover, 1/3 of patients had bony prominence – the transition of the acetabular arch into the iliac wing, which was represented by the bone edge rounded downwards. The correlation analysis between the AI values and the length of the acetabular arch, measured on X-ray and CT scans, showed a strong positive correlation which was r = 0.96 and 0.98, respectively.

Regression analysis showed that the coefficient of determination (R^2) for the correlation of AI and acetabular arch length measured on X-ray and CT scans was 0.93 and 0.96, respectively. It had no significant differences between the linear and quadratic models, which brought the studied attributes closer to the linear regression (Fig. 3). Approximation is considered very good, because more than 90% of sample can be substantiate by the regression formula. Thus, reliable radiometry of such parameters of the acetabular anatomy as AI and the length of the acetabular arch can be adequately performed without the use of CT, which will significantly reduce the radiation dose to the child.

Table 1

Values of acetabular deformity in patients with varying severity of hip dysplasia

Parameter	Patients with hip dysplasia M±SD (min-max) Me (25–75%)	Contralateral joint M±SD (min-max) Me (25–75%)
AI according to X-ray, deg.	40.6±5.0 (31.0–51.0) 41.0 (37.0–44.0)	20.6±2.0 (15.0–24.0) 20.5 (19.0–22.8)
AI according to CT, deg.	39.9±4.9 (30.0–52.0) 41.0 (36.0–43.0)	20.5±2.0 (14.0–23.0) 20.3 (19.0–22.5)
Arch length according to X-ray, mm	14.1±3.5 (10.0–22.1) 13.2 (11.3–16.7)	19.3±2.6 (14.3–24.3) 19.4 (17.2–21.4)
Arch length according to CT, mm	13.8±3.4 (10.0–21.7) 13.0 (10.9–16.2)	19.1±2.3 (13.9–24.1) 18.8 (16.7–21.1)
Bony prominence: – present – absent	 37% 63%	 100% –

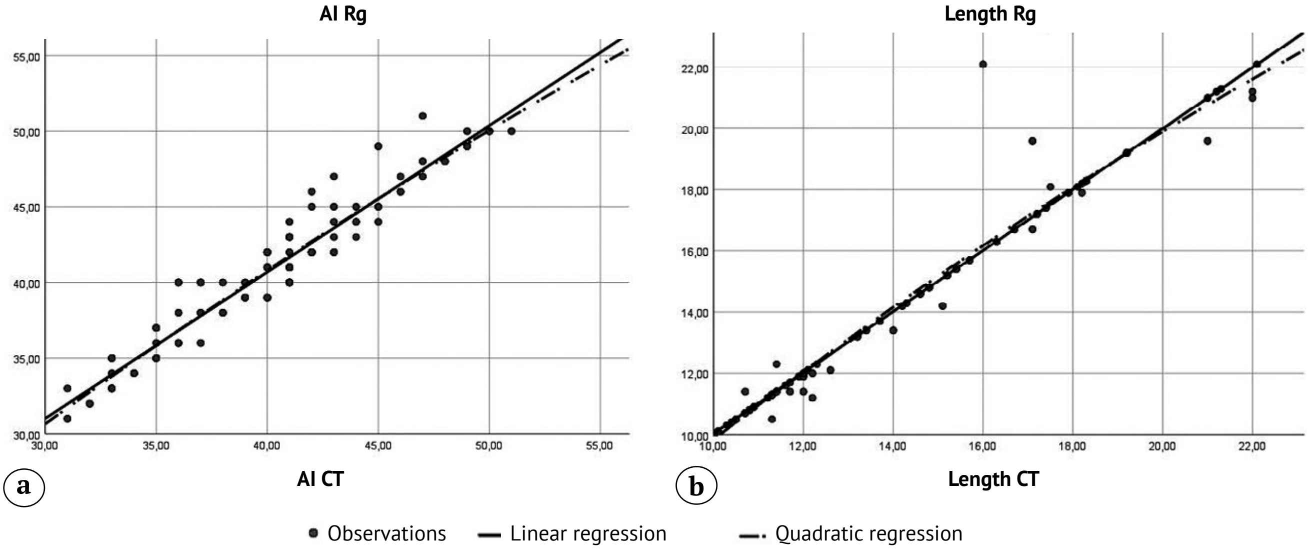

Fig. 3. Results of regression analysis reflecting the correlation between:
a — values of AI measured in X-rays and CT scans;
b — values of acetabulum arch length measured in X-rays and CT scans

Patients were divided into two groups depending on the severity of dysplastic instability of the hip in order to study possible variants of acetabular deformity in more details. The first group enrolled 90 patients (90 hip joints) with grade II dysplasia, i.e., hip subluxation. The second group included 110 patients (110 hip joints) with grade III-IV dysplasia, i.e., hip dislocation.

Table 2 shows the results of radiometric analysis performed in patients with hip subluxation.

Analysis of the X-ray anatomy of the acetabulum in children with hip subluxation (Tönnis grade II) showed that 44% of patients (40 hip joints) had a distinct bony prominence, AI values did not exceed 35°, and the acetabular arch shortening was 25% or more compared to the healthy joint. In 56% of cases (50 hip joints), the bony prominence was not detected, AI was greater than 35° and was not accompanied by the shortening of the acetabular arch. Correlation and regression analysis showed strong positive correlation (r = 0.66) between AI and the length of the acetabular arch. Coefficient of determination was 0.44 with approximation value of 44% (Fig. 4).

The results of the radiometric analysis of the above-mentioned parameters in patients with hip dislocation are presented in Table 3.

Table 2

Values of acetabular deformity in children with Tönnis grade II hip dysplasia

Parameter	Patients of Group I M±SD (min-max) Me (25–75%)	Contralateral joint M±SD (min-max) Me (25–75%)
AI according to X-ray, deg.	39.2±5.2 (31.0–50.0) 40.0 (35.0–42.0)	20.6±2.0 (15.0–24.0) 20.5 (19.0–22.8)
Arch length according to X-ray, mm	16±3 (10.0–22.1) 15.7 (14.3–18.2)	19.2±2.6 (14.3–24.1) 19.3 (14.3–21.4)
Bony prominence: – present – absent	 44% 56%	 100% –

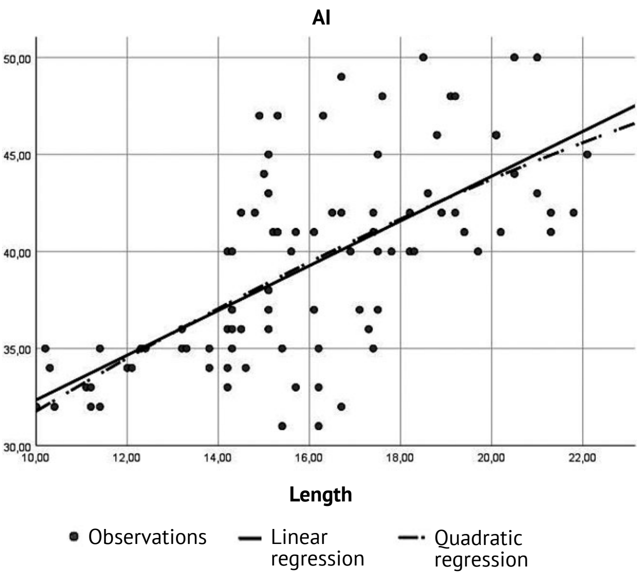

Fig. 4. Results of regression analysis reflecting the correlation between AI values and acetabulum arch length in children with hip subluxation

Table 3

Values of acetabular deformity in children with Tönnis grade III-IV hip dysplasia

Parameter	Patients of Group II M±SD Me (25–75%)	Contralateral joint M±SD Me (25–75%)
AI according to X-ray, deg.	39.0±5.3 (31.0–51.0) 39.0 (35.0–43.0)	20.6±2.0 (15.0–24.0) 20.5 (19.0–22.8)
Arch length, mm	15.3±3.0 (10.0–22.1) 15.1 (13.1–17.7)	19.2±2.6 (14.3–24.1) 19.3 (14.3–21.4)
Bony prominence: – present – absent	 51.8% 48.2%	 100% –

Analysis of the X-ray anatomy of the acetabulum in children with hip dislocation (Tönnis grade III-IV) showed that 51.8% of patients (57 hip joints) had bony prominence. In 38 patients (34.5%) AI values did not exceed 35° and the ace-tabular arch shortening was detected. AI values in 19 patients (17.3%) were more than 35° in association with the acetabular arch shortening compared to the contralateral joint. In 48.2% of cases (53 hip joints) the transition of the acetabulum into the iliac wing was not detected, AI values did not exceed 35° and the acetabular arch was extended. Correlation and regression analysis showed moderate positive correlation (r = 0.4) between AI and the length of the acetabular arch. Coefficient of determination was 0.16 with approximation value of 16% (Fig. 5).

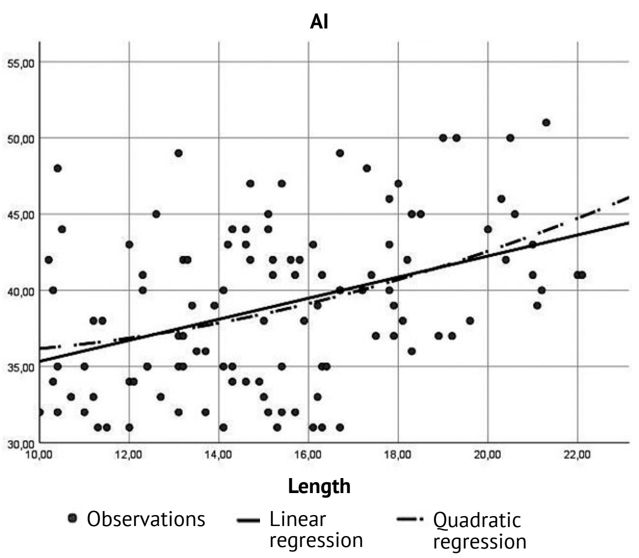

Fig. 5. Results of regression analysis reflecting the correlation between AI and acetabulum arch length in children with hip dislocation

Low coefficient of determination indicates rather large variability of possible acetabular deformities in children with hip dislocation.

Thus, basing on the studied X-ray anatomy of the acetabulum, as well as on the correlation and regression analysis, we can distinguish three most common types of acetabular deformity in case of hip dysplasia in young children.

1. Moderate underdevelopment of the acetabular arch with AI values ≤ 35°, shortening of the acetabular arch, and the presence of bony prominence. This type occurred in 44% of cases of hip subluxation and in 34.5% of cases of dislocation.

2. Marked underdevelopment of the acetabular arch with AI values > 35°, extended acetabular arch and the absence of bony prominence. This type was found in 56% of cases of hip subluxation and in 48.2% of cases of dislocation

3. Marked underdevelopment of the acetabular arch with AI values > 35°, shortening of the acetabular arch and the presence of bony prominence. This type of deformity occurred in 17.3% of observations only in children with hip dislocation.

DISCUSSION

Severity of this pathology, as well as inaccurate diagnostics and conservative treatment of children with varying severity of hip dysplasia inevitably lead to the need of various surgical interventions performed to restore correct relations in the hip joint and to provide conditions for its correct development and remodeling as the child grows [14, 15, 16, 17].

Nowadays, the verification of diagnosis and determination of severity of the hip deformation in children over 1 year represent no difficulties [5, 6, 18]. At the same time, the overwhelming majority of orthopedic surgeons, when planning a surgery, perform an X-ray assessment of severity of the acetabular arch underdevelopment with the use of AI values, deformity of the proximal femur, as well as the severity of the femoral head dislocation in relation to the acetabulum by integral indicators and available international classifications [19, 20, 21, 22, 23]. It should be pointed out that the latter reflect only the character of incorrect relations in the hip without the detailed verification of possible types of deformities of the pelvic and femoral components of the joint. This sufficiently limits the perception of pathologic disorders in the affected joint and makes it possible to decide only upon the necessity of arthrotomy followed by intraarticular manipulations. Nowadays, the choice of pelvic osteotomy technique depends on the surgeon, his experience and preferences, since the available scientific data show the high efficacy of techniques applied in the international orthopedic practice for surgical correction of dysplastic acetabulum both in the mid-term and long-term follow-up period [24, 25, 26, 27]. Russian scientists developed the working classification of hip dysplasia.

Thus, I.F. Akhtyamov and O.A. Sokolovskii distinguish two types of dysplasia – femoral and pelvic [28]. V.D. Makushin and M.P. Teplen'kii developed more detailed classification of hip dysplasia based on two variants of pathological state – stable and unstable. Both of them are subdivided into femoral, acetabular and mixed forms, while the unstable type is also characterized by the direction of the femoral head dislocation in relation to the acetabulum [29]. Both classifications are intended to define a methodological approach when choosing the way of correction of the pelvic, femoral, or both components of the joint. In our opinion, the main disadvantage of these classifications is the lack of characteristics of the acetabular deformity types. Nowadays, there is a sonographic classification of hip dysplasia in children in the first year of life developed by R. Graf which reflects both hip joint relations and types of deformity of the acetabular structures [30]. This classification prompted us to perform this study.

In our opinion, basing on the most frequent types of acetabular deformities in children with Tönnis grade II-IV hip dysplasia verified during the present study, it is reasonable to include them in the existing classification, presented in Figure 6.

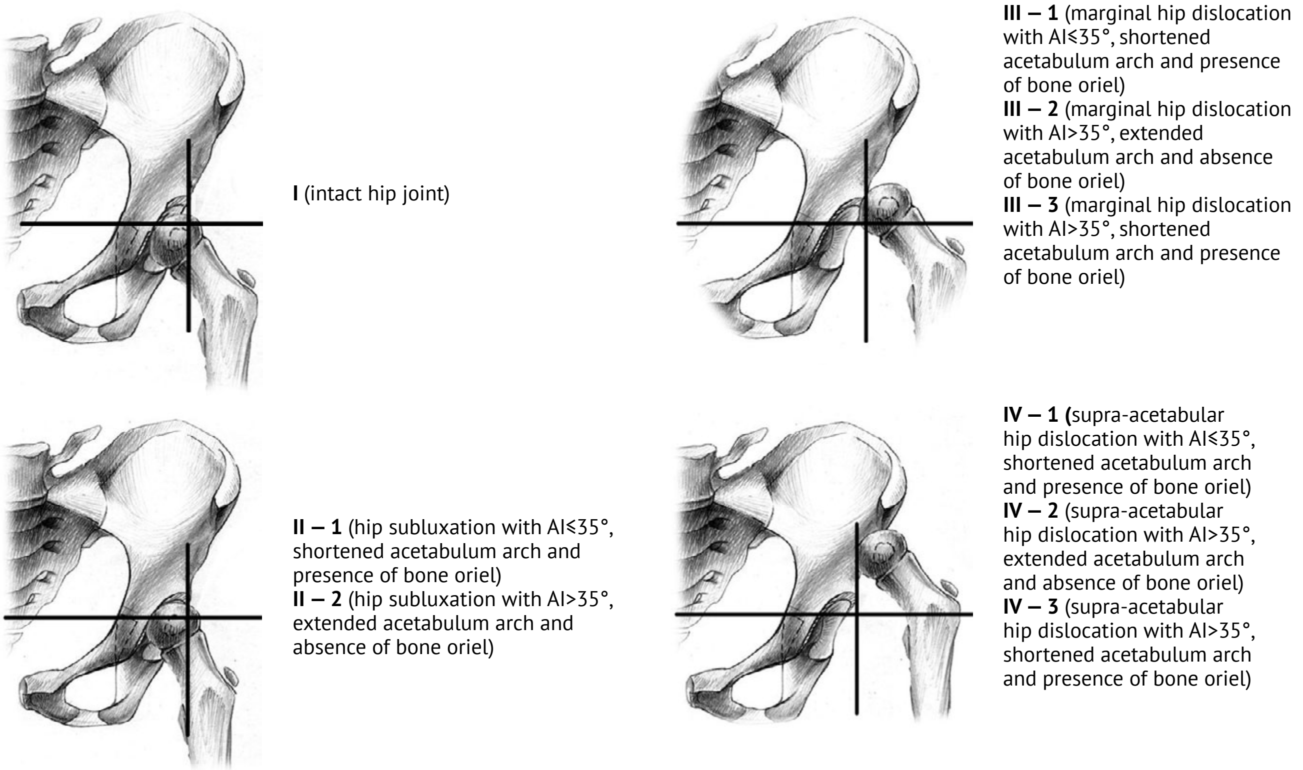

Fig. 6. Supplemented Tönnis classification of hip dysplasia severity

CONCLUSION

Performed radiological and anatomical analysis of the acetabulum in young children with varying severity of hip dysplasia, based on the study of severity of underdevelopment of the acetabular arch, its length, as well as the presence or absence of bony prominence, revealed three most common types of acetabular deformity, which are characterized by: 1 — moderate underdevelopment of the acetabular arch (AI ≤ 35°), its shortening and the presence of bony prominence; 2 — severe underdevelopment of the acetabular arch (AI > 35°), its sufficient length and the absence of bony prominence; 3 — severe underdevelopment of the acetabular arch (AI > 35°), its shortening and the presence of bony prominence.

In our opinion, the proposed additions to the existing classification of hip dysplasia developed by D. Tönnis can become the basis for an algorithm of technique selection for surgical correction of the acetabulum in children with varying severity of hip dysplasia, which is a priority for our further study.

DISCLAIMERS

Author contribution

Pavel I. Bortulev — conception and design of the study, collection and processing of material, data statistical processing, literature review, writing the draft.

Tamila V. Baskaeva — collection and processing of material, text editing.

Sergei V. Vissarionov — text editing.

Dmitriy B. Barsukov — collection and processing of material, text editing.

Ivan Yu. Pozdnikin — collection and processing of material, text editing.

Makhmud S. Poznovich — collection and processing of material, text editing.

All authors have read and approved the final version of the manuscript of the article. All authors agree to bear responsibility for all aspects of the study to ensure proper consideration and resolution of all possible issues related to the correctness and reliability of any part of the work.

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Ethics approval. Not applicable.

Consent for publication. Written consent was obtained from legal representatives of children for publication of relevant medical information and all of accompanying images within the manuscript.

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Authors' information

✉ *Pavel I. Bortulev* — Cand. Sci. (Med.)
Address: 64-68, Parkovaya st., St. Petersburg, Pushkin, 196603, Russia
https://orcid.org/0000-0003-4931-2817
e-mail: pavel.bortulev@yandex.ru

Tamila V. Baskaeva
https://orcid.org/0000-0001-9865-2434
e-mail: tamila-baskaeva@mail.ru

Sergei V. Vissarionov — Dr. Sci. (Med.), Professor
https://orcid.org/0000-0003-4235-5048
e-mail: vissarionovs@gmail.com

Dmitriy B. Barsukov — Cand. Sci. (Med.)
https://orcid.org/0000-0002-9084-5634
e-mail: dbbarsukov@gmail.com

Ivan Yu. Pozdnikin — Cand. Sci. (Med.)
https://orcid.org/0000-0002-7026-1586
e-mail: pozdnikin@gmail.com

Makhmud S. Poznovich
https://orcid.org/0000-0003-2534-9252
e-mail: poznovich@bk.ru