



Effect of Radical Hip Reconstruction in Children With Hip Subluxation on Sagittal Balance and Type of Vertical Posture: Mid-Term Results

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Abstract

Background. Hip instability in the form of hip subluxation, regardless of its etiology, leads not only to the formation of excessive pelvic anteversion and lumbar hyperlordosis, but also to the early development of hip osteoarthritis. The lack of information in the world literature on possible changes in sagittal balance parameters in this category of patients after triple pelvic osteotomy requires such studies.

Aim of the study is to evaluate the spino-pelvic sagittal balance and the type of vertical posture in children with hip subluxation of different genesis after radical reconstructive intervention in the mid-term follow-up period.

Methods. The study is based on the analysis of clinical and X-ray results of 50 patients (50 hip joints) aged 10 to 17 years with hip subluxation operated on between 2018 and 2019. The patients were divided into two groups: group I consisted of 30 patients (30 hip joints) with Crowe type I dysplasia; group II consisted of 20 patients (20 hip joints) with Legg-Calvé-Perthes disease. All children underwent triple pelvic osteotomy.

Results. Different approaches to triple pelvic osteotomy in patients with hip instability of various genesis allowed to significantly affect the spino-pelvic sagittal balance and the type of vertical posture. In all patients there was a decrease in the sacral slope value, spino-sacral angle, the magnitude of lumbar lordosis, as well as a change in the sagittal vertical axis value from strongly negative to neutral.

Conclusions. Analysis of mid-term results of surgical treatment of children with hip instability in the form of hip subluxation and Legg-Calvé-Perthes disease using 3D modeling and prototyping of individual guides showed that the triple pelvic osteotomy leads to the reduction of both excessive pelvic anteversion and lumbar hyperlordosis, resulting in the transformation of physiologically disadvantageous hyperlordotic type of vertical posture into harmonious one.

Keywords: children, hip dysplasia, Legg-Calvé-Perthes disease, hip subluxation, spino-pelvis balance, triple pelvic osteotomy, 3D modeling.

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Влияние радикальной реконструкции тазобедренного сустава у детей с подвывихом бедра на показатели сагиттального баланса и тип вертикальной осанки: среднесрочные результаты

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Реферат

Актуальность. Нестабильность тазобедренных суставов в виде подвывиха бедра вне зависимости от его этиологии приводит не только к формированию чрезмерной антеверсии таза и гиперлордозу поясничного отдела позвоночника, но и к раннему развитию коксартроза. Отсутствие в мировой литературе сведений о возможных изменениях параметров сагиттального баланса у данной категории пациентов после выполнения тройной остеотомии таза диктует необходимость проведения таких исследований.


Цель исследования — оценить состояние сагиттальных позвоночно-тазовых соотношений и тип вертикальной осанки у детей с подвывихом бедра различного генеза после выполнения радикального реконструктивного вмешательства в среднесрочном периоде наблюдения.


Материал и методы. Исследование основано на анализе результатов клинико-рентгенологического обследования 50 пациентов (50 тазобедренных суставов) в возрасте от 10 до 17 лет с подвывихом бедра, прооперированных в период с 2018 по 2019 г. Пациенты были разделены на две группы: группу I составили 30 пациентов (30 тазобедренных суставов) с дисплазией I степени по Crowe; группу II — 20 пациентов (20 тазобедренных суставов) с болезнью Легга – Кальве – Пертеса. Всем детям выполнена тройная остеотомия таза.

Результаты. Различные подходы к выполнению тройной остеотомии таза у пациентов с нестабильностью тазобедренного сустава различного генеза позволили значительно повлиять на состояние сагиттальных позвоночно-тазовых соотношений и тип вертикальной осанки. У всех пациентов произошло уменьшение угла наклона крестца, позвоночно-крестцового угла, величины поясничного лордоза, а также изменение значения сагиттальной вертикальной оси из резко негативного к нейтральному.

Заключение. Анализ среднесрочных результатов хирургического лечения детей с нестабильностью тазобедренного сустава в виде подвывиха бедра и болезнью Легга – Кальве – Пертеса с применением технологии 3D-моделирования и прототипирования индивидуальных шаблонов-направителей показал, что выполнение тройной остеотомии таза приводит к уменьшению как избыточной антеверсии таза, так и гиперлордоза поясничного отдела позвоночника, в результате чего происходит трансформация физиологически невыгодного гиперлордотического типа вертикальной осанки в гармоничный.

Ключевые слова: дети, дисплазия тазобедренного сустава, болезнь Легга – Кальве – Пертеса, подвывих бедра, позвоночно-тазовые соотношения, тройная остеотомия таза, 3D-моделирование.

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BACKGROUND

The concept of forming a certain type of vertical posture in humans is based on the magnitude of the lumbar lordosis, which, in turn, directly depends on the value of the only individual morphological pelvic index, pelvic incidence (PI) [1, 2, 3, 4]. It has been determined that there is an excessive pelvic anteversion at high PI values, which is expressed in an increase in sacral slope (SS) and a decrease in pelvic tilt (PT) values [5]. As a result of such radiographic anatomical condition, a hyperlordotic type of vertical posture is formed. On the contrary, when PI values are low, pelvic retroversion is observed, characterized by SS decrease and PT increase with the formation of the hypolordotic type of vertical posture. Thus, it can be stated that the formation of human vertical posture is primarily influenced by the spatial position of the pelvis in the sagittal plane.

Recent studies on the state of sagittal balance in children and adults with various hip pathologies have proven the formation of the types of lumbar lordosis and vertical posture in general that are unfavorable for such patients in terms of the development and course of degenerative changes in the lumbosacral spine. In particular, it has been found that children with hip instability due to hip subluxation, which most often has either a dysplastic genesis or is formed as a result of Legg-Calvé-Perthes disease (LCPD), are characterized by the hyperlordotic type of vertical posture [6, 7]. It should be noted that children with dysplastic hip subluxation have a characteristic increase in PI values compared to the values in the asymptomatic population, while children with LCPD have a slight decrease in PI values. Despite these differences, we can conclude that hip subluxation, regardless of the etiology and PI values, leads to an excessive anterior rotation of the pelvis and, as a consequence, hyperlordosis of the lumbar spine. The obtained data once again prove that any pathologic changes in the hip have a direct impact on the anatomy of the pelvis, which together form the severity of the lumbosacral lordosis. Today, it has been proven by numerous authors that the only way to restore the lost stability in the hip due to its subluxation in senior children with hip dysplasia and LCPD is radical reconstructive surgery, and the optimal technique is the triple pelvic osteotomy [8, 9, 10, 11, 12]. However, studies investigating possible

changes in the type of vertical posture and sagittal balance parameters in children with hip instability of various genesis are sporadic [13].

Aim of the study is to evaluate the spino-pelvic sagittal balance and the type of vertical posture in children with hip subluxation of different genesis after radical reconstructive intervention in the mid-term follow-up period.

METHODS

Design of the study

Type of the study: multicenter cohort retrospective study.

Inclusion criteria:

- age between 10 and 17 years;
- no history of hip surgery, including soft tissue and minimally invasive surgeries;
- instability of one hip joint in the form of hip subluxation of dysplastic genesis and LCPD;
- absence of severe deformity of joint components requiring intra-articular manipulations and modeling resection;
- no need for surgical correction of the spatial position of the proximal femur via its osteotomy;
- no spinal pathology of any etiology, neuro-orthopedic, genetic and systemic diseases.

Exclusion criteria:

- age less than 10 and more than 18 years;
- bilateral pathologic process;
- pronounced asphericity of the femoral head and/or sharply pathologic radiometric values of the proximal femur;
- hip joint effusion of any genesis;
- flexion-adduction contracture in the hip joint;
- congenital malformations of the spine, including neutral or alternating, verified neurological, systemic and genetic diseases.

The study enrolled 50 patients (50 hips) aged 10 to 17 years (13.0 ± 2.3 years) with hip instability in the form of hip subluxation, treated at the Center's clinic between 2018 and 2019. All patients underwent triple pelvic osteotomy to eliminate the instability of the hip joint and restore correct radiographic anatomical relationships. Children were divided into two groups: I — 30 patients (30 hips) with dysplastic hip subluxation (Crowe grade I); II — 20 patients (20 hips) with hip subluxation as a result of LCPD. Treatment results were evaluated at 40.5 ± 3.9 months after the surgery.

The clinical study was conducted according to the classic well-known procedure. In order to obtain objective information on the presence of impairments in the execution of everyday functions directly related to pain in the lumbosacral spine, all patients completed the Oswestry disability questionnaire [14] (excluding the section "Sexual life" due to the age limit). Taking this into account, the calculations were performed according to the authors' recommendations, which refer to cases of not completing any of the sections. Radiological methods included hip X-rays in the anteroposterior and axial views in the supine position, teleradiography of the spine in the sagittal view in the standing position with maximum capture of the lower extremities, and multislice spiral computed tomography (MSCT).

Radiometry of the following parameters was performed: acetabular vertical inclination angle (Sharp angle), Wiberg angle, neck-shaft angle (NSA), antetorsion angle (AA), bone coverage (BC), acetabular retroversion index (ARI), thoracic kyphosis (TK), global lumbar lordosis (GLL), pelvic incidence (PI), sacral slope (SS), pelvic tilt angle (PT), sagittal vertical axis (SVA) and spine-sacral angle (SSA). Three-dimensional planning of the upcoming intervention was performed for all patients at the preoperative stage in order to accomplish accurate individual

intraoperative reorientation of the acetabulum after osteotomy of the pubic, sciatic, and iliac bones. Reduction of the acetabular fragment in group I patients was performed in the anterior external direction due to the underdevelopment of the anterior superior acetabular rim, which is typical for hip dysplasia. In addition, taking into account literature data on the state of sagittal spino-pelvic balance (SSPB) in children without musculoskeletal diseases and patients with hip subluxation of various genesis [15, 16, 17], as well as the important role of PI in the formation of lumbar lordosis and vertical posture in general, group I patients underwent additional posterior translation of the acetabular component to reduce PI values by no more than 15 mm. In group II patients, acetabular rotation was exclusively external because there was a deficit of lateral coverage of the femoral head (Fig. 1).

Immediately before surgery, patient-specific templates were 3D-printed, which were subsequently used during surgery. Their use provided determination of the exact level of iliac bone osteotomy allowing an individual reduction maneuver to change the spatial position of the acetabulum to the optimal individual value to restore the stability of the hip (Fig. 2).

Radiometry of the obtained data was performed in Surgimap v. 2.3.2.1 (USA) software.

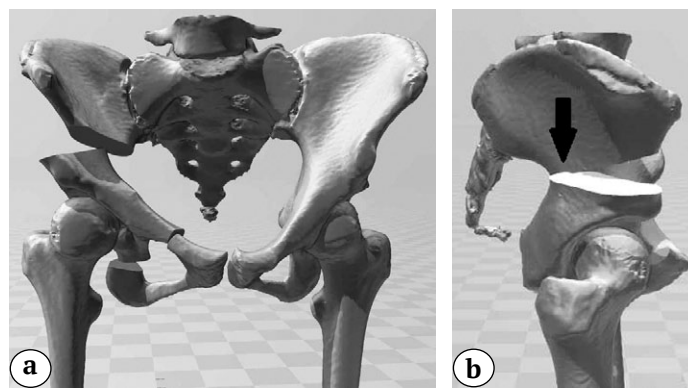


Fig. 1 (a, b). Stage of triple pelvic osteotomy with 3D modeling of optimal individual acetabular correction: a, b – external anterior rotation of the acetabular fragment in a patient with Crowe type I right hip dysplasia (arrow indicates posterior translation)

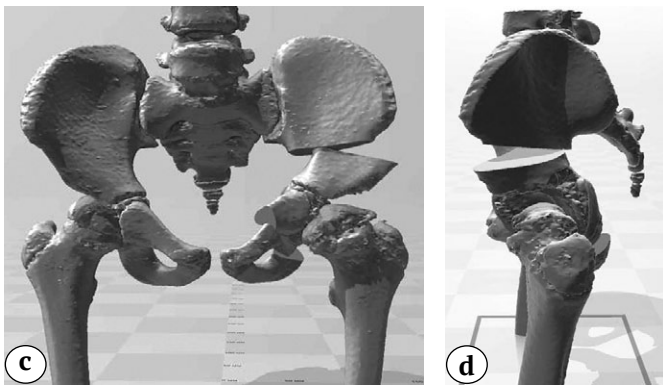


Fig. 1. (c, d). Stage of triple pelvic osteotomy with 3D modeling of optimal individual acetabular correction:
c, d — external rotation of the acetabular fragment in a patient with hip subluxation in LCPD

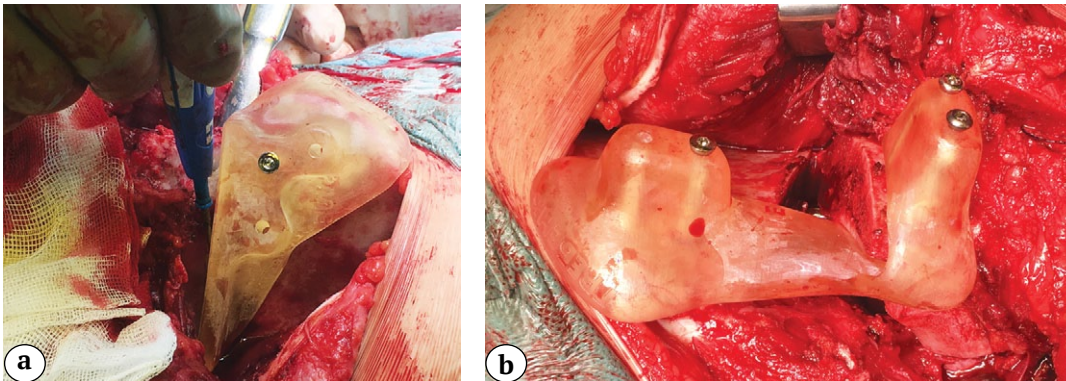


Fig. 2. Intraoperative application of customized templates:
a — to determine the level and direction of the iliac body osteotomy;
b — to achieve an individual adequate correction of the acetabular position during reduction

Statistical analysis

Statistical analysis was performed using Excel 2010 and SPSS Statistic v.26, (SPSS Inc. Chicago, Illinois, USA) software. Descriptive statistics were used to calculate arithmetic mean (M), standard deviations (SD), median (Me) with 25th and 75th percentiles (Q1-Q3). Correlation analysis was performed using Pearson's chi-square test (strength of correlation was considered as $0.01 \leq \rho \leq 0.29$ — weak; $0.30 \leq \rho \leq 0.69$ — moderate; $0.70 \leq \rho \leq 1.00$ — strong). Regression analysis (paired linear and quadratic regression model) was performed to assess the degree of influence of one attribute on another, as well as to determine the variant of influence. Examination of the sample share was carried out according to the values of the coefficient of multiple determination (R^2).

RESULTS

On admission to the department, all patients had complaints typical for hip subluxation, i.e. lameness and moderate pain in the affected hip.

This resulted in psychoemotional discomfort and social disadaptation of children due to their inability to live a normal life like their peers (inability to participate in active games and sports). The mean values of the Oswestry disability index were $19.1 \pm 9.6\%$ in group I and $17.4 \pm 6.9\%$ in group II, which indicates the presence of pathologic changes in the lumbar spine that do not require therapy, but require restrictions in the activity and physical exercises. Shortening of the lower limb was 1.4 ± 0.5 cm in patients of both study groups. Goniometry revealed changes in the range of motion on the affected side typical for each etiologic cause of hip subluxation, which manifested in restricted hip abduction common to all patients included in the study, as well as in excessive rotational movements in group I patients and limited internal rotation in group II patients.. Examination of physiologic spinal curvatures revealed lumbar hyperlordosis in 22 (73.3%) patients of group I and in 12 children (60%) of group II. Changes in the radiographic anatomical structure of the hip and parameters describing the

sagittal balance in patients with Crowe grade I hip subluxation and in LCPD have been described in details in previous studies [6, 7].

All patients underwent triple pelvic osteotomy to restore the stability of the hip joint, taking into account the details of its performance described above. All patients underwent complex rehabilitation starting the first day after the surgery. In the mid-term follow-up period only 2 (7%) patients of group I and 1 (5%) patient of group II still had complaints of gait disorders, which, first of all, was due to the poor execution of rehabilitation procedures. Hip pain was resolved in patients of both study groups. Average physiologic values of the range of motion in the operated joint were achieved in all patients (Table 1).

Clinical study of the state of physiologic spinal curvature in patients of both groups showed a consistent decrease in the severity of the initial hyperlordosis. The mean values of the Oswestry disability index were $2.8 \pm 3.1\%$ and $2.4 \pm 2.6\%$ in groups I and II, respectively, which may indicate an improvement in the biomechanical state and balance in the lumbosacral spine.

Average values describing the anatomy and orientation of the acetabulum, as well as the stability of the hip joint as a whole, were within reference values in all patients after radical surgical correction of the pelvic component and elimination of hip instability after triple pelvic osteotomy. The absence of significant defects in the correction of the acetabular fragment position in both frontal and horizontal planes after triple pelvic osteotomy demonstrates the high efficiency of the application of individual guides for the reduction to ensure the optimal position of the acetabulum (Table 2).

Analysis of the results showed 95% identity between the planned and achieved correction of the acetabular fragment after performing the reduction reorientation maneuver, which is especially relevant in patients with dysplastic hip instability due to the need for multiplanar correction (Fig. 3).

The study of the values of pelvic indices, the values of physiologic spine curvatures and their correlations in group I patients showed that the correction of hip subluxation with posterior translation of the acetabulum by triple pelvic osteotomy resulted in a significant decrease in the values of the pelvic incidence, as well as a decrease in the values of the sacral slope to its normal value in the asymptomatic population. As a result of the surgery, the initially existing lordosis (hyperlordosis) of the lumbar spine approached physiological normal values. The values of the spine-sacral angle did not differ from those of healthy children. This indicates not only the return of the trunk as a whole to the mid-sagittal line in relation to the pelvis, but also the derotation of the

Table 1
Hip goniometry values at mid-term follow-up, deg., M±SD

Motion	Group I	Group II
Flexion	113±3	115±2
Abduction	39±3	28±3
Internal rotation	42±3	18±3
External rotation	45±4	35±3

Table 2
Main X-ray parameters of the anatomical structure and stability of the hip, sagittal balance in patients of both groups

Parameter	Group I, M±SD Me (Q1–Q3)	Group II, M±SD Me (Q1–Q3)	Reference values in asymptomatic population of children [18, 19, 20]
Sharp angle, deg.	36.2±4.8 36 (32–40)	34.0±3.3 34 (30.8–35.5)	35–45
Wiberg angle, deg.	32.7±3.9 33 (30–35)	35.4±4.0 36 (32.0–38.5)	25–40
BC, %	93.3±5.9 95 (90–100)	98.5±2.4 100 (95–100)	85–100
ARI, %	4.8±3.2 5 (3–6)	3.0±3.0 2.2 (1–5)	до 20

Main X-ray parameters of the anatomical structure and stability of the hip, sagittal balance in patients of both groups

Parameter	Group I, M±SD Me (Q1–Q3)	Group II, M±SD Me (Q1–Q3)	Reference values in asymptomatic population of children [18, 19, 20]
NSA, deg.	141.5±5.3 141.5 (138.3–145.0)	138.5±5.8 140 (135.0–141.8)	125–145
AA, deg.	35.5±3.7 36.7 (32.7–38.0)	15.3±2.0 15 (13.3–16.0)	10–30
PI, deg.	43.1±4.0 43.2 (41.6–46.0)	44.2±5.2 44.7 (42.6–51.1)	45.4±10.7
PT, deg.	4.1±2.1 4.3 (3.0–6.3)	6.2±2.4 6 (5.7–9.0)	10.3±6.5
SS, deg.	39.0±3.6 39 (36.9–40.7)	38.0±5.6 37 (33.8–42.8)	35.4±8.1
TK, deg.	35.0±4.3 35 (32.8–37.2)	34.4±3.8 35 (31.8–36.7)	37.1±9.9
GLL, deg.	44.9±7.2 44.2 (41.3–49.3)	41.6±6.2 42.2 (35.9–46.0)	39.6±12.4
SVA, mm	0.8±10.0 0.9 (-6.6–6.6)	0.3±9.0 4.2 (-8.2–6.0)	0.1±2.3
SSA, deg.	132.8±7.0 134 (130–138)	130.5±8.3 131 (124–138)	130.4±8.1

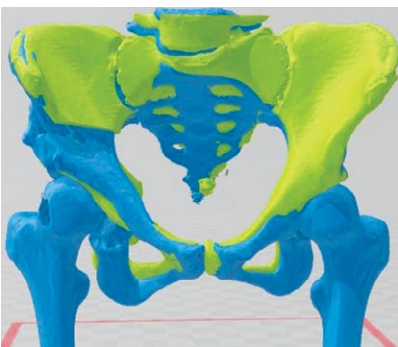


Fig. 3. Identity of planned individual (green) and achieved (blue) acetabular positions after reorienting reduction in a patient with dysplastic hip subluxation

latter from the position of excessive anteversion. At the same time, the preoperative global negative imbalance characterized by a pronounced posterior displacement of SVA in relation to the sacral promontory approached the state of neutral compensated balance, as evidenced by SVA values in the mid-term follow-up period after radical reconstructive surgery (Fig. 4).

The above-mentioned values also changed in group II patients after surgical treatment, resulting in a slight increase in the morphologic PI value and an average 6% decrease in SS values compared with initial ones. The values of all pelvic indices came close to the average values in healthy children. Due to the change in the spatial position of the pelvis in the sagittal plane, the lumbar lordosis decreased compared to the preoperative values. In addition, similarly to group I patients, the values of the spine-sacral angle did not differ from the norm, and the values of SVA came close to neutral from negative, indicating stabilization of the global balance of the trunk in the sagittal plane (Fig. 5).

The correlation analysis shown in Figure 6 revealed direct strong positive correlations between the main sagittal balance values in both study groups, indicating the restoration of kinematic links maintaining the dynamic phenomenon of sagittal balance.

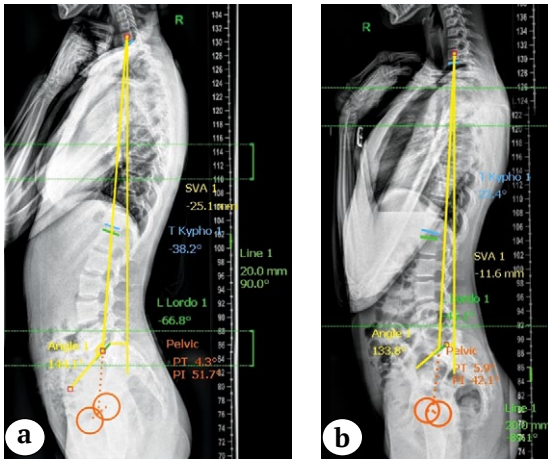


Fig. 4. Teleradiographs of the spine in the sagittal view of a 14-year-old patient with Crowe type I left hip dysplasia before radical reconstruction (a) and 38 months after (b). Explanation in the text

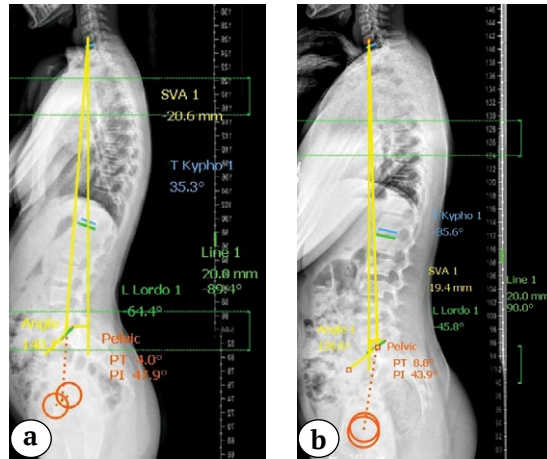


Fig. 5. Teleradiographs of the spine in the sagittal view of an 11-year-old patient with right hip subluxation as a result of LCPD before radical reconstruction (a) and 36 months after (b). Explanation in the text

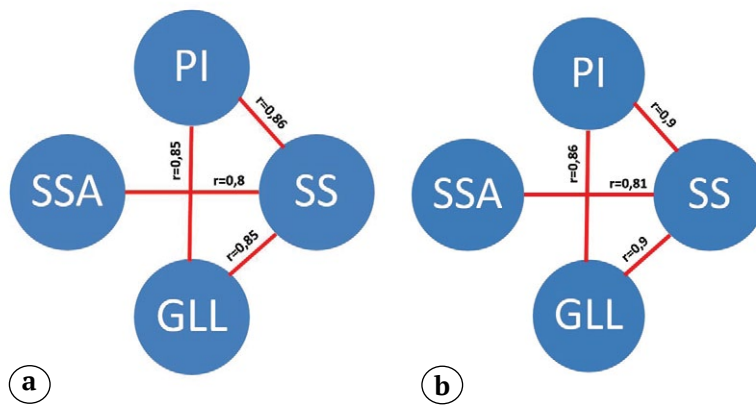


Fig. 6. Correlations between sagittal balance values in patients with hip subluxation of dysplastic genesis (a) and in case of LCPD (b)

The correlation between the main SSPB in children with Crowe grade I dysplasia in the mid-term follow-up period is shown in the results of regression analysis (Fig. 7).

The coefficient of determination (R^2) of the indicated SSPB values was higher than 0.73 and did not differ significantly from the linear and quadratic models. This brought the signs closer to the linear regression. More than 70% of the sample can be justified by this regression formula, so the approximation can be recognized as good.

Regression analysis results, indicating the correlation between the main SSPB in children with hip subluxation in LCPD at mid-term follow-up, are shown in Fig. 8.

The coefficient of determination (R^2) for SSPB was above 0.75 and did not differ significantly from the linear and quadratic models. This brought the signs closer to the linear regression. More than 75% of the sample could be justified by this regression formula, so the approximation could also be considered good.

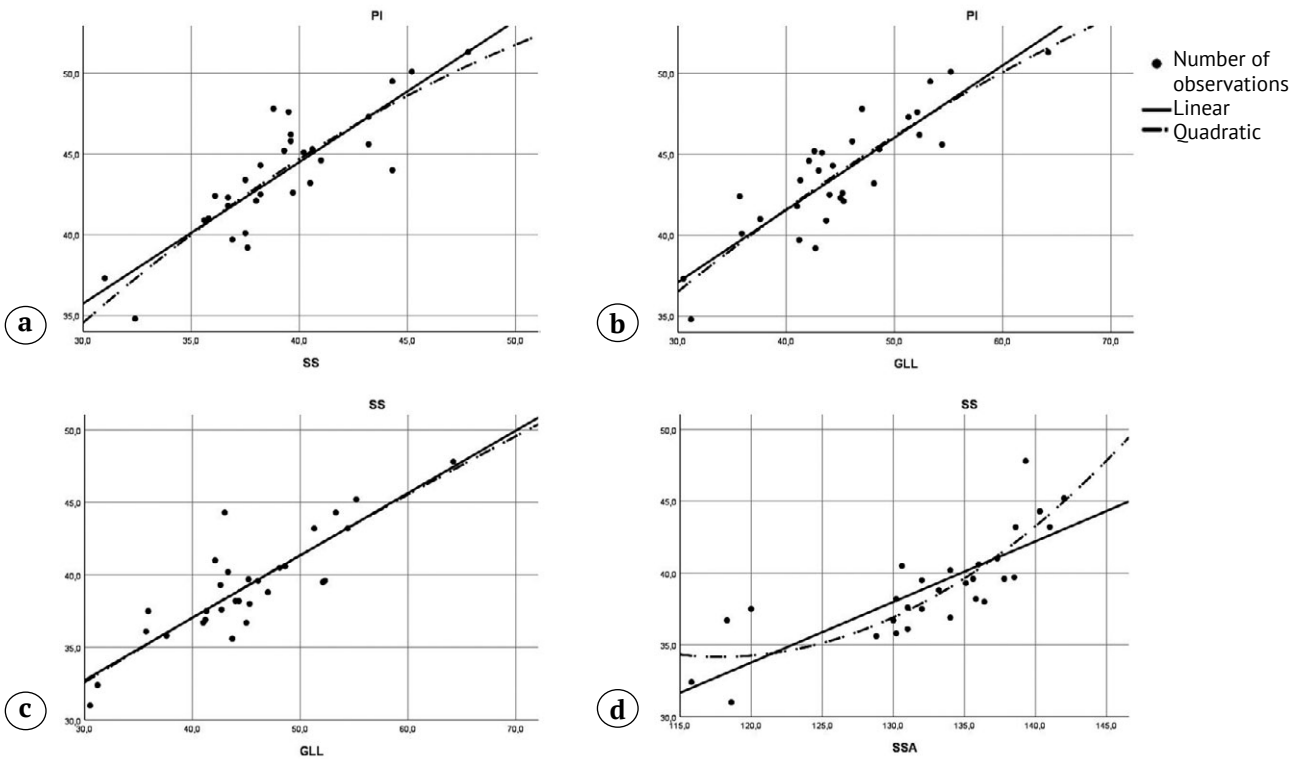


Fig. 7. Relationship between SPSB in group I patients: a – between PI and SS; b – between PI and GLL; c – between SS and GLL; d – between SSA and SS

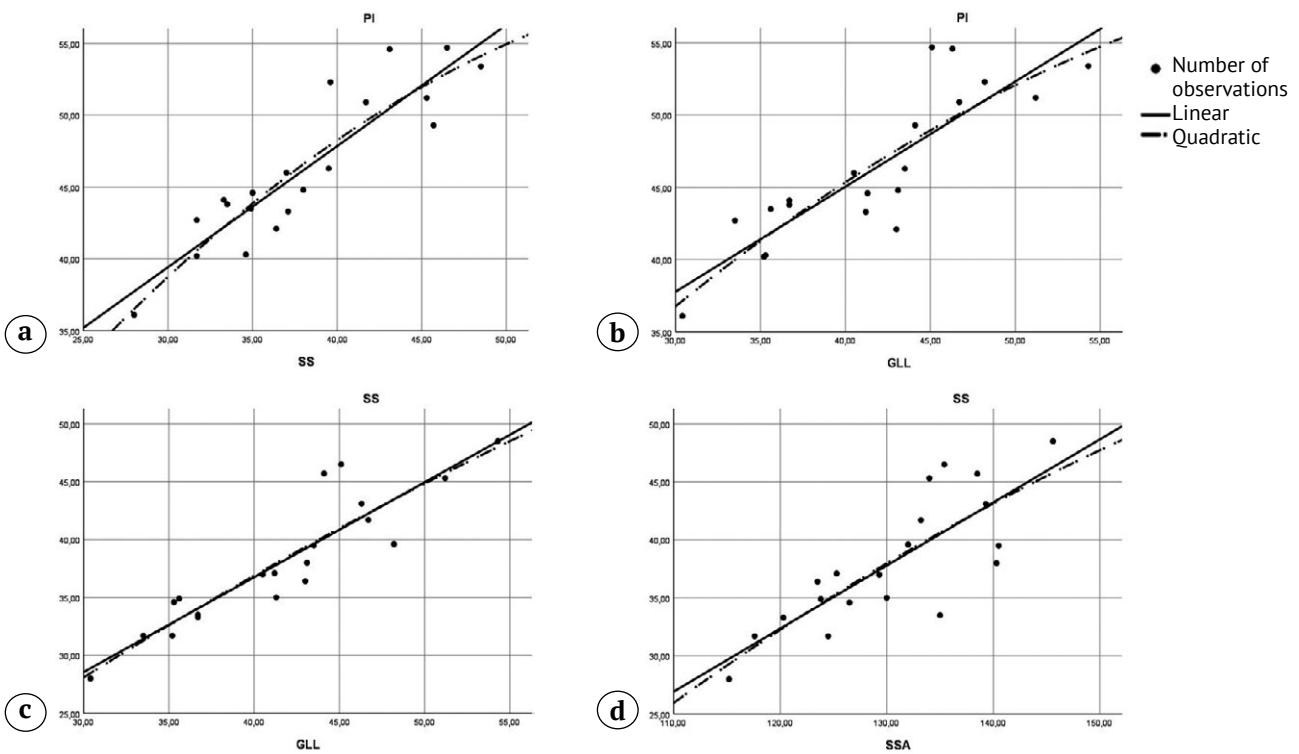


Fig. 8. Results of regression analysis showing the relationships between spino-pelvic sagittal balance in group II patients: a – between PI and SS; b – between PI and GLL; c – between SS and GLL; d – between SSA and SS

On the basis of the obtained data, we can conclude that due to achievement of the optimal individual position of the acetabulum and restoration of stability of the hip joint in general, all patients have transformed the hyperlordotic type of vertical posture into a harmonious one, according to the improved classification of P. Rousouly [21], in which the occurrence and course of degenerative-dystrophic changes in the lumbosacral spine will not differ from similar processes in the asymptomatic people.

DISCUSSION

Since the first detailed description of SSPB followed by the identification of possible ways of lumbar lordosis formation, on which the type of human vertical posture depends, the interest of the world orthopedic community in this topic has been growing annually [5, 22]. Currently, the literature details possible variants of sagittal balance changes in adult patients with various orthopedic spine diseases, femoroacetabular impingement, and hip osteoarthritis [23, 24, 25, 26, 27]. Moreover, there are studies on the nuances of acetabular component positioning during the performance of total hip arthroplasty that depend on SSPB [28, 29, 30, 31].

Nowadays, there are few publications on the state of sagittal balance in children with various pathologies of the musculoskeletal system [6, 7, 32, 33, 34, 35]. At the same time, the studies devoted to changes in the state of SSPB after reconstructive surgeries are sporadic [13, 36].

In one of the studies, dedicated to evaluation of changes in SSPB and vertical posture after transposition of the greater trochanter in patients with its hypertrophy, I.Yu. Pozdnyukov et al. concluded that this operation led to a decrease in excessive pelvic anteversion and hyperlordosis. As a result, the hyperlordotic vertical posture changes into a harmonious one [36]. At the same time, such changes in the type of lumbar lordosis, in our opinion, are primarily associated with changes in the biomechanics of the gluteus medius muscle, since PI values in this category of patients had no differences both before and after surgery.

We found the only article dedicated to assessment of the possibilities of surgical balance correction in children with hip instability [13]. According to the results of the study, the authors conclude that various reconstructive surgeries on the pelvic and femoral articular components result in the reduction of the existing hyperlordosis by decreasing PI values. However, it should be noted that the different nosological and age groups of patients, the presence of various types of contractures in the hip joint, and the performance of corrective osteotomy of the femur in the vast majority of cases did not allow us to adequately assess the true impact of the techniques of surgical stabilization of the hip on the change in SSPB and vertical posture. In addition, no patient with hip instability of dysplastic etiology underwent triple pelvic osteotomy.

In our study, different approaches to triple pelvic osteotomy in patients with hip subluxation of different genesis allowed to significantly affect SSPB and vertical posture. In particular, in patients with Crowe grade I dysplasia, adequate antero-superior coverage of the femoral head combined with posterior translation of the acetabulum led to a decrease in PI, SS, SSA, and lumbar lordosis values until they reached the physiologic normal values.

These results confirm the findings of a team of authors from Japan, who found that the patients with acetabular dysplasia were characterized by pelvic anteversion and hyperlordosis, and anterior and external rotation of the acetabulum contributed to the reduction of the latter and was preventive for the development of "hip-spine" syndrome [37].

In addition, according to the correlation analysis, the direct positive correlation between PI and SS increased from 0.3 to 0.86, which may indicate the restoration of complex kinematic links in the system "hip joints - lumbar spine". In patients with subluxation of the femur in LCPD, the reorientation of the acetabulum, taking into account its normal development, during triple pelvic osteotomy was performed strictly in an external direction in order to achieve a BC of at least 95% according to the basic principle of "containment therapy" in this category of patients [38, 39, 40].

As a result of the surgical intervention, there were no significant changes in PI values, while SS, SSA and lumbar lordosis values reached the average physiologic levels. Correlation analysis showed an increase in the direct positive correlation between PI and GLL from 0.6 to 0.9, which also indicates the restoration of links in the kinematic system "hip joints - lumbar spine". Patients in both study groups showed a persistent tendency to transform the negative imbalance into a neutral one, as evidenced by the dynamics of changes in SVA values. In addition, regardless of the etiology of hip subluxation after surgical stabilization of the hip, taking into account the features of its performance, there was a conversion of the hyperlordotic type of vertical posture into a harmonious type, which enables prevention of the development of "hip-spine" syndrome and early degenerative dystrophic changes in the lumbosacral spine in this category of patients.

CONCLUSIONS

Analysis of mid-term results of surgical treatment of children with hip instability in the form of hip subluxation and Legg-Calvé-Perthes disease using 3D modeling and prototyping of individual guides showed that the triple pelvic osteotomy leads to the reduction of both excessive pelvic anteversion and lumbar hyperlordosis. The achieved optimal correction of the acetabulum with restoration of hip stability ensured the transformation of the physiologically disadvantageous hyperlordotic type of vertical posture into a harmonious one, which is confirmed by bringing the main radiographic parameters of sagittal balance closer to the values in the asymptomatic population of children.

DISCLAIMERS

Author contribution

Bortulev P.I. — study concept and design, data collection and processing, literature search and analysis, writing the article.

Vissarionov S.V. — study design, drafting the article.

Barsukov D.B. — data collection and processing, drafting the article.

Pozdnikin I.Yu. — data collection and processing, drafting the article.

Poznovich M.S. — data collection and processing, drafting the article.

Baskaeva T.V. — data collection, drafting the article.

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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