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# THE INFLUENCE OF TRIPLE PELVIC OSTEOTOMY ON THE SPINE-PELVIS RATIOS IN CHILDREN WITH DYSPLASTIC SUBLUXATION OF THE HIP

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**Introduction.** Triple pelvic osteotomy is an effective surgical treatment for dysplastic subluxation of the hip in children aged above 12 years. However, modern studies did not assess the indicators of spine-pelvis ratios, sagittal profile of the spine in children with dysplastic subluxation of the hip following surgical treatment, and possibility of change on these values during the operation.
**Aim.** This study aimed to evaluate the effectiveness of the improved technique of performing triple pelvic osteotomy on children with dysplastic subluxation of the hip.
**Materials and methods.** We analyzed the x-ray images and surgical treatment of 35 female patients (44 hip joints) aged 13 to 18 years with dysplastic subluxation of the hip between 2016 and 2018. The patients were divided into two groups: the main group consisted of 20 patients (25 hip joints) who underwent surgical treatment that had taken into account the state of sagittal spine-pelvis ratios according to the improved method using personalized navigation templates, and the control group consisted of 15 patients (19 hip joints) who received surgical treatment according to the generally accepted method.
**Results.** In addition to the typical clinical and radiological abnormalities of the dysplastic subluxation of the hip in 90% of patients in both groups, there were changes in the sagittal balance in the form of excessive pelvic anteversion and lumbar hyperlordosis. One year postoperatively, patients in the main group showed significant changes ($p < 0.05$) in the state of sagittal spine-pelvis ratios in the form of a decrease in the pelvic base angle, which led to the achievement of the average values of the angle of inclination of the sacral slope (SS) and the value of global lumbar lordosis. On the other hand, these radiological parameters in patients in the control group remained within the preoperative values.
**Conclusion.** The improved technique of triple pelvic osteotomy provides conditions for the reduction of pelvic anteversion and restoration of the sagittal profile of the spine ($p < 0.05$). The use of personalized navigation templates allows for the most accurate multiplane correction of the acetabulum. It is necessary to include a specialized x-ray examination in the preoperative planning to assess the state of sagittal spine-pelvis ratios.

**Keywords:** children; subluxation of the hip; sagittal spino-pelvic ratios; triple pelvic osteotomy; 3D-prototyping; navigation templates.

# ВЛИЯНИЕ ТРОЙНОЙ ОСТЕОТОМИИ ТАЗА НА ПОЗВОНОЧНО-ТАЗОВЫЕ СООТНОШЕНИЯ У ДЕТЕЙ С ДИСПЛАСТИЧЕСКИМ ПОДВЫВИХОМ БЕДРА

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**Введение.** Тройная остеотомия таза является эффективной методикой хирургического лечения детей с диспластическим подвывихом бедра старше 12 лет. Однако отсутствуют современные исследования, посвященные оценке показателей позвоночно-тазовых соотношений и сагиттального профиля позвоночника у детей с диспластическим подвывихом бедра после хирургического лечения, а также возможностей изменения данных величин в ходе операции.

**Цель работы** — оценить эффективность усовершенствованной методики тройной остеотомии таза у детей с диспластическим подвывихом бедра.

**Материалы и методы.** Были проанализированы результаты углубленного рентгенологического обследования и хирургического лечения 35 пациентов женского пола (44 тазобедренных сустава) в возрасте от 13 до 18 лет с диспластическим подвывихом бедра, получавших лечение с 2016 по 2018 г. Пациенты были разделены на две группы: основную группу составили 20 пациентов (25 тазобедренных суставов), которым хирургическое лечение проводили с учетом состояния сагиттальных позвоночно-тазовых соотношений по усовершенствованной методике с использованием персонифицированных навигационных шаблонов; контрольную группу составили 15 пациентов (19 тазобедренных суставов), получавших хирургическое лечение по общепринятой методике.

**Результаты.** Помимо типичных клинико-рентгенологических нарушений, характерных для диспластического подвывиха бедра, у 90 % пациентов обеих групп наблюдались изменения со стороны сагиттального баланса в виде избыточной антеверсии таза и гиперлордоза поясничного отдела позвоночника. Через год после хирургического лечения у пациентов основной группы произошли достоверные ($p < 0,05$) изменения сагиттальных позвоночно-тазовых соотношений в виде уменьшения угла наклона таза, что привело к достижению среднестатистических значений угла наклона крестца и величины поясничного лордоза. У пациентов контрольной группы вышеуказанные рентгенологические показатели остались в пределах дооперационных значений.

**Заключение.** Усовершенствованная методика тройной остеотомии таза обеспечивает условия для уменьшения антеверсии таза и восстановления сагиттального профиля позвоночника ($p < 0,05$). Персонифицированные навигационные шаблоны позволяют осуществлять максимально точную многоплоскостную коррекцию вертлужной впадины. Необходимо включение в предоперационное планирование специализированного рентгенологического обследования с целью оценки состояния сагиттальных позвоночно-тазовых соотношений.

**Ключевые слова:** дети; подвывих бедра; сагиттальные позвоночно-тазовые соотношения; тройная остеотомия таза; 3D-прототипирование; навигационный шаблон.

## Introduction

Hip dysplasia manifests through a number of pronounced anatomical changes resulting from impaired physiological development of the joint during the ante- and postnatal periods [1]. In the absence of a timely diagnosis and adequate conservative treatment, as the child grows, the femoral head becomes decentralized, resulting in subluxation, which leads to severe static-dynamic disorders and pain syndrome as early as adolescence [2]. In patients with dysplastic subluxation of the hip, we observe clinical and radiological changes in the sagittal profile of the spinal column and a disruption of the vertebral-pelvic ratios. These pathological processes lead to the formation of a vertical posture that falls outside generally accepted standard parameters. One of the fundamental parameters leading to these changes is excessive pelvic anteversion [3].

Surgical technologies aimed at stabilizing dysplastic hip joints have a long history of development, from various options for correcting hip osteotomies, bone canopies, and acetabuloplasty to rotational osteotomies of the pelvis [4–6]. Pelvic osteotomy using Dr. Salter's technique (1957) is the gold standard for the treatment of children younger than 7 years who suffer from dysplastic instability of the hip joints. At older ages, however, the possibility of acetabular fragment rotation is significantly reduced due to the rigidity of the pubic symphysis ligaments. This situation served as a prerequisite for the development of alternatives for the transposition of the acetabulum with dysplastic hip subluxation. In 1977, D. Sutherland and R. Greenfield developed and described a double pelvic osteotomy. In 1991, D. Sutherland and M. Moore published clinical and radiological outcomes of pelvic osteotomy: they excluded the mandatory basic element of the Salter operation and performed an osteotomy somewhat more medially to the fusion of the pubic bone branches and, resected the bone fragment.

The technique of double pelvic osteotomy developed by Yu.I. Pozdnikin (1983) includes, in addition to the iliac bone osteotomy, a periacetabular resection of the pubic bone followed by a “closed” fracture of the pubic-sciatic synchondrosis during rotation. This procedure extends the possibilities for correcting the acetabulum. It should be noted that the clinical application of this technique is limited by the patient’s age, and one of its disadvantages is lateralization of the hip joint.

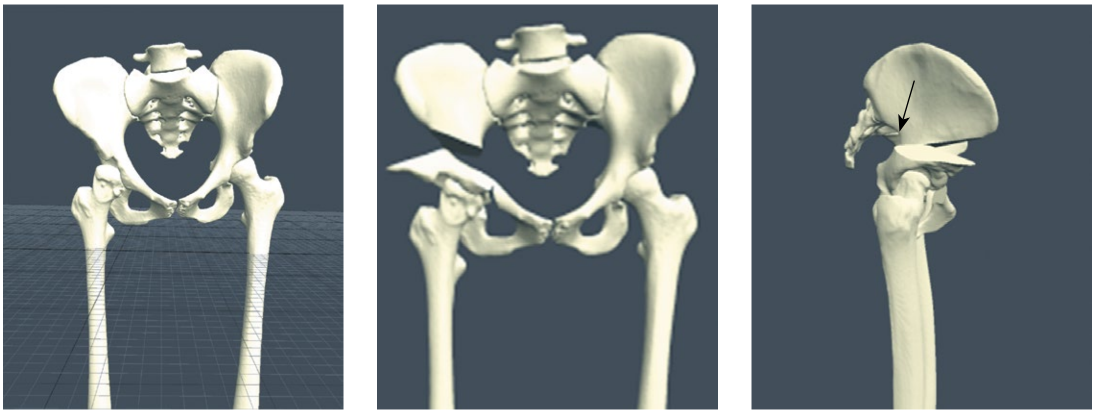
At present, the most widespread techniques include variants of triple pelvic osteotomy in the H. Steel and D. Tönnis modification with the functioning Y-shaped cartilage, and the periacetabular pelvic osteotomy according to R. Ganz, which are performed after the completion of pelvic bone growth [7–9]. A significant drawback of the above operational techniques is the need to use several surgical approaches for the pelvic bone osteotomy by changing the position of the patient on the operating table during the intervention, as well as severe deformity of the pelvic half-ring after surgery. The periacetabular osteotomy technique by R. Ganz (1980), despite its obvious advantages, such as maintaining the posterior pelvic column intact, the stability of the pelvis configuration, and the possibility of early axial load, is extremely difficult technically. In addition, acetabular hollows cannot be medialized during the operation. Given the disadvantages, Russian scientists have developed technologies for triple pelvic osteotomy that have found broad application among orthopedic surgeons working in specialized hospital departments [10–12]. Analyses of the long-term results of triple pelvic osteotomy in children with dysplastic instability of the hip joint have shown that triple pelvic osteotomy is the most appropriate method of surgical correction of the spatial position of the acetabulum.

To date, there have been no postoperational assessment studies of indicators of the vertebral-pelvic ratios and the sagittal profile of the spine in children with dysplastic subluxation of the hip, including the possibilities of changing these values during surgery. Therefore, doctors from the Hip Joint Pathology Department of the Turner Scientific Research Institute for Children’s Orthopedics of the Ministry of Health of the Russian Federation improved the triple pelvic osteotomy technique for the treatment of children with dysplastic hip subluxation (application for the grant of a patent for invention from the Russian Federation No. 2018132663, September 12, 2018).

**The aim of this study** was to evaluate the effectiveness of an improved technique for triple pelvic osteotomy in children with dysplastic subluxation of the hip.

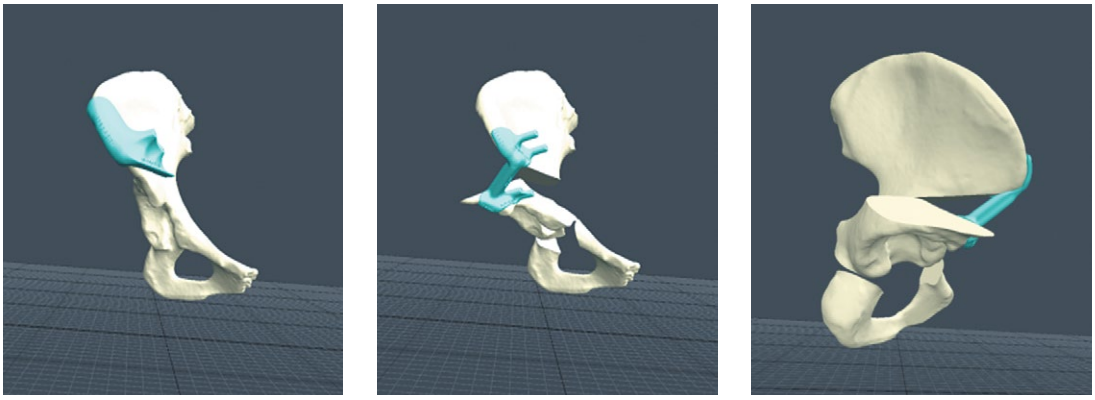
## Materials and methods

The study included 35 female patients (44 hip joints) aged from 13 to 18 years (mean age 15.5 ± 1.38 years) with hip joint instability of dysplastic genesis in the form of hip subluxation. They were treated in the institute’s clinic from 2016 to 2018. The criteria for inclusion were age from 13 to 18 years; unilateral or bilateral hip subluxation; a true collum-diaphyseal angle not more than 140 degrees; an antetorsion angle of the proximal femur not more than 45 degrees; congenital or acquired constant spinal column pathologies; neurological disorders; systemic and genetic diseases; and voluntary informed consent from patients and their parents to participate in this study. The criteria for exclusion of patients were hip dislocation, including marginal; a true collum-diaphyseal angle more than 140 degrees; an angle of proximal femur anterior torsion more than 45 degrees that required corrective osteotomy of the femur; congenital spinal or idiopathic scoliosis; or verified neurological, systemic, or genetic diseases. All the children were divided into two groups. The study group consisted of 20 patients (25 hip joints), who underwent a triple pelvic osteotomy using an improved technique, taking into account the state of the sagittal balance of the spine and the vertebral-pelvic ratios. Unilateral subluxation was found in 15 (75%) patients, and bilateral subluxation was found in 5 (25%) patients. The control group consisted of 15 children (19 hip joints), who underwent surgical intervention (triple pelvic osteotomy) according to the standard technique; that is, the acetabulum rotation was calculated only on the basis of roentgeometry results for hip joints. Unilateral subluxation was found in 11 (73.4%) patients; bilateral subluxation was found in 4 (26.6%). In order to objectify patient complaints



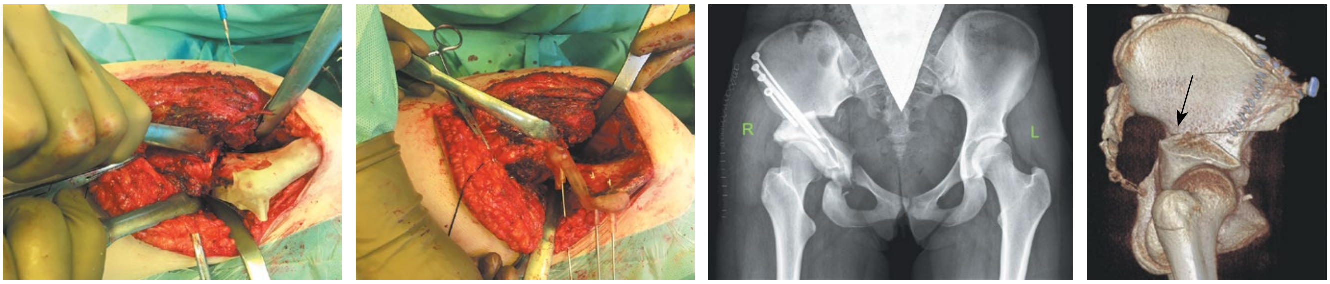
*a* *b* *c*

**Fig. 1.** Planning of the surgical intervention using the PME Planner program: *a* — segmentation of the image obtained after multislice CT; *b* — osteotomy of the pelvic bones and planning the correction of the acetabular position; *c* — planning the necessary translation of the posterior acetabular fragment



*a* *b* *c*

**Fig. 2.** Virtual creation of personalized navigation patterns in the PME Planner program: *a* — a template for performing the ilium body osteotomy; *b*, *c* — template for intraoperative fixation of the acetabular fragment in the position of the calculated correction in all planes




*a* *b* *c* *d*

**Fig. 3.** Clinical application of a personalized navigation template: *a* — an intraoperative pattern for using a template to calculate the exact location of the ilium body osteotomy; *b* — intraoperative picture of using the template to fix the spatial position of the acetabulum in the position of the calculated correction; *c*, *d* — radiological and multislice CT result of triple pelvic osteotomy using the chosen technique

and obtain the most complete information about the functional state of the hip joint, all the patients completed the teen-adapted scale — the Harris hip score questionnaire, from which the goniometry section was excluded as the most difficult for assessment by the child itself. X-ray examination methods included an X-ray of the hip joints in the anteroposterior projection and in the Lauenstein position, computed tomography (CT), and a lateral panoramic radiograph of the spinal column $C_1$–$S_1$ with the femurs in the standing position before the operation and 1 year after the operation. During the study, indicators such as vertical inclination angle of the acetabulum (Sharp angle), Wiberg angle, collum-diaphyseal angle, proximal femur angle of antetorsion, degree of bone covering (DBC), size of thoracic kyphosis and global lumbar lordosis (according to Cobb), pelvic incidence (PI), sacral slope (SS), pelvic tilt (PT) angle, and global sagittal balance (SVA) were evaluated. For triple pelvic osteotomy in children with dysplastic instability of the hip joints, we chose the method developed by the Turner Scientific Research Institute for Children's Orthopedics (Kamosko, MM, 2007). After the CT study, during the preoperational period all the patients from the study group underwent 3D modeling with subsequent computer planning of the upcoming surgery with Polygon Medical Engineering (PME) Planner software (Fig. 1). The patients from the control group underwent a visual correction of acetabulum position during the triple pelvic osteotomy in order to eliminate the hip subluxation.

Taking into account the information in the literature and the experience of our own observations regarding sagittal vertebral-pelvic ratios in healthy children and patients with hip joint pathology [3, 13–15], we believe we have improved the triple pelvic osteotomy technique. The main task was not only to achieve stability of the hip joint, but also to improve the sagittal vertebral-pelvic ratios. A distinctive feature of this operation was not the angular resection of the ilium, but instead a transverse periacetabular osteotomy from top to bottom, with the onset below the anterior superior iliac spine and the posterior acetabular fragment displacement after rotational acetabulum transposition (see Fig. 1).

The displacement of the acetabular component was calculated on the basis of the PI indicator, which is the only permanent anatomical indicator and can only be changed by injury or surgery [16]. The acetabular fragment was moved posteriorly between 0.5 and 1.5 cm. The technique of prototyping personalized navigation patterns (fused deposition modeling on a PICASO 3D Designer PRO 250 printer) was to ensure maximum accuracy during the surgical intervention and to limit the possibility of hypo- or hypercorrection of the pelvic component and to prevent the development of femoroacetabular impingement. The use of these patterns during surgical intervention allowed us to perform the osteotomy of the ilium body and fixation of bone fragments exactly in accordance with the previously calculated correction (Fig. 2, 3).

The obtained data were evaluated using Surgimap v. 2.2.15. The statistical analysis was performed using IBM SPSS v.23. The level of significance of differences was determined using the nonparametric Mann–Whitney *U* test with a reliability of at least $p < 0.05$. The correlation analysis was performed using the Pearson criterion.

## Results

At the time of admission to the clinic, the patients from both groups complained of pain in the area of the affected hip joint and gait disturbance. The average Harris hip score for the patients from the study and control groups was 62.4 ± 4.1 and 64 ± 5.4, respectively. The relative shortening of the lower limb was 1.3 ± 0.5 cm (for unilateral lesion). In addition, all patients noted restrictions in their physical activity. The restrictions were mainly characteristic of adolescents (an inability to participate in active sports, such as aerobics or dancing). These restrictions were the cause of pronounced psycho-emotional discomfort. The mean values of the amplitude of active hip joint movements in the patients in the study group were as follows: flexion 110° ± 5°, abduction 34° ± 6°, extension 10° ± 5°, internal rotation 60° ± 10°, and external rotation 50° ± 10°. The patients from the control group showed similar data in terms of flexion (105° ± 9°), abduction (38° ± 4°), extension (15° ± 7°), internal rotation (5° ± 12°), and external rotation (50° ± 8°).

A change in the sagittal profile of the spinal column, manifested as hyperlordosis of the lumbar spine, was observed in 17 (85%) patients in the study group and in 12 (80%) patients in the control group.

The preoperational results of radiological examinations in both groups (average values of Sharp and Wiberg angles, cranial displacement, cervical-diaphyseal angle, proximal femur anesthetic angle, thoracic kyphosis, global lumbar lordosis (GLL) and sagittal vertebral-pelvic ratios [PI, PT, SS, SVA]) are presented in Table 1.

The absence of significant differences ($p > 0.05$) in the data obtained allowed for further comparisons. Table 1 shows that both groups had values characterizing the pelvic and femoral

*Table 1*

Preoperational indicators of the spatial orientation of the acetabulum, proximal femur, hip joint stability, sagittal spine profile, and vertebral-pelvic ratios in children with dysplastic hip subluxation from the study and control groups

| Indicators | Study group ($M \pm SD$) | Control group ($M \pm SD$) |
|---|---|---|
| Sharp angle, degrees | 56.9 ± 4.0 | 57.6 ± 5 (51–63) |
| Wiberg angle, degrees | –4.2 ± 2.8 | –5.0 ± 3.7 |
| DBC,% | 55.8 ± 6.3 | 53.0 ± 7.8 |
| Cranial displacement, cm | 0.8 ± 0.3 | 0.7 ± 0.4 |
| CDA, degrees | 133.8 ± 3.9 | 134.8 ± 3.5 |
| AA, degrees | 38.5 ± 6.7 | 37.3 ± 6.5 |
| PI, degrees | 52.5 ± 11.1 | 52.1 ± 10.5 |
| PT, degrees | 9.1 ± 9.5 | 11.1 ± 9.1 |
| SS, degrees | 43.3 ± 4.5 | 42.7 ± 3.7 |
| TK, degrees | 33.6 ± 11.0 | 35.1 ± 11.6 |
| GLL, degrees | 58.4 ± 6.5 | 57.3 ± 4.0 |
| SVA, degrees | –6.4 ± 18.8 | –5.7 ± 16 |

*Abbreviations:* DBC: degree of bone coverage; CDA: collum-diaphyseal angle; AA: the angle of proximal femur antetorsion; PI: pelvic incidence; PT: pelvic tilt; SS: sacral slope; TK: thoracic kyphosis; GLL: global lumbar lordosis; SVA: global sagittal balance.

*Table 2*

Amplitude of movements in the hip joints of patients in both groups after surgical treatment

| Movement | The amplitude of movements in patients from the study group ($M \pm SD$) | The amplitude of movements in patients from the control group ($M \pm SD$) |
|---|---|---|
| Flexion, degrees | 116.0 ± 4.7 | 115.0 ± 5.1 |
| Abduction, degrees | 38.0 ± 3.5 | 36.0 ± 2.9 |
| Internal rotation, degrees | 30.0 ± 3.7 | 30.0 ± 3.1 |
| External rotation, degrees | 45.0 ± 4.2 | 45.0 ± 3.8 |

components of the joint that are typical for dysplastic pathology [17]. The excessive pelvis anteversion in 32 (91%) patients from both groups manifested as an increase in the SS index and a decrease in the PT index. Changes in the state of the physiological spine curves in the form of hyperlordosis were registered in the lumbar region only. In just 3 (9%) patients from both groups, the indices of sagittal vertebral-pelvic ratios remained within average values. The SVA indicator, which characterizes the state of global sagittal balance, was negative in both groups. Correlation analyses in patients from both groups showed the presence of a strong correlation only between GLL and SS values ($r = 0.68$, $p < 0.05$). The correlation between PI and SS was weak ($r = 0.38$, $p < 0.05$).

The results of surgical treatment were evaluated after 1 year. Patients from both groups received specialized rehabilitation treatment starting in the early postoperative period [18]. At the time of the examination, 2 (10%) patients from the study group and 1 (10%) patient from the control group complained of discomfort in the region of the operated joint and gait disturbance that occurred only after considerable physical exertion. The remaining patients from both groups had no complaints. The average Harris hip score in patients from the study and control groups was 91 ± 4.8 and 90 ± 3.6, respectively. The goniometry data are presented in Table 2.

Table 2 shows that the indices of hip joint goniometry almost reached physiological values

*Table 3*

Indicators of spatial acetabulum orientation, proximal femur, hip joint stability, sagittal spine profile, and vertebral pelvic ratios in patients from both groups 1 year after surgical treatment

| Indicators | Study group ($M \pm SD$) | Control group ($M \pm SD$) |
|---|---|---|
| Sharp angle, degrees | 35.1 ± 4.7 | 32.1 ± 8.1 |
| Wiberg angle, degrees | 32.0 ± 4.1 | 37.0 ± 9.2 |
| DBC,% | 95.0 ± 4.2 | 100.0 ± 5.1 |
| Cranial displacement, cm | 0.2 ± 0.13 | 0.3 ± 0.15 |
| CDA, degrees | 133.8 ± 3.9 | 134.8 ± 3.5 |
| AA, degrees | 38.5 ± 6.7 | 37.3 ± 6.5 |
| PI, degrees | 40.1 ± 10* | 55.3 ± 9.3 |
| PT, degrees | 5.1 ± 8.3* | 12.1 ± 9.6 |
| SS, degrees | 35.0 ± 4.5* | 43.2 ± 4.1 |
| TK, degrees | 31 ± 6 | 35.7 ± 10.7 |
| GLL, degrees | 45.3 ± 6.0* | 59.8 ± 3.6 |
| SVA, degrees | 5.7 ± 14.1* | –6.2 ± 16.7 |

*Abbreviations:* DBC: degree of bone coverage; CDA: collum-diaphyseal angle; AA: the angle of proximal femur antetorsion; PI: pelvic incidence; PT: pelvic tilt; SS: sacral slope; TK: thoracic kyphosis; GLL: global lumbar lordosis; SVA: global sagittal balance. * significance of the difference between the study and control groups ($p < 0.05$).

in patients from both groups 1 year after surgical treatment. According to the results of a visual assessment, the state of physiological spinal curvatures in the patients from the study group tended to normalize, whereas the control group preserved the hyperlordosis of the lumbar spine. In the course of a triple pelvic osteotomy by the improved technique in 18 (90%) patients, the posterior acetabulum was displaced 1–1.5 cm, which resulted in a 10°–15° decrease in PI. In 2 (10%) patients, who did not show significant deviations from the average values of the vertebral-pelvic ratios, the posterior acetabulum was displaced no more than 0.5 cm to prevent anterior acetabulum displacement during rotation.

Table 3 presents the results of radiological examinations (average values of Sharp and Wiberg angles, cranial displacement values, cervical-diaphyseal angle, proximal femur antetorsion angle, thoracic kyphosis, GLL, and indices of sagittal vertebral-pelvic ratios [PI, PT, SS, SVA]) of patients from both groups 1 year after surgery.

Based on the data from Table 3, it can be concluded that 1 year after triple pelvic osteotomy, the average values of radiological indicators characterizing the spatial position of the acetabulum and the average values of integral indicators describing the orientation and ratio of the pelvic and femoral joint components varied, but were in the range of normal values in both groups [17]. At the same time, the pelvic ratios in the study group compared with the control group changed significantly ($p < 0.05$) toward a decrease in PI that led to a decrease in pelvic anteversion and, as a result, lumbar spine hyperlordosis. In most cases, the study group showed improvements in the SVA indicator. In addition, the correlation analysis showed a stronger connection between PI and SS indices ($r = 0.67$, $p < 0.05$), which could indicate restoration of the kinematic chain in the hip joint — lumbosacral spine system (Fig. 4).

## Discussion

Congenital and acquired diseases of both the spine and hip joints can lead to changes in sagittal vertebral-pelvic ratios [19, 20]. To date, when planning the correction of spinal deformities, vertebrologists have always calculated spinal-pelvic ratios to achieve a stable physiological sagittal profile after surgery [16, 21]. A number of authors have shown that changes in pelvic indices cause changes in the sagittal profile of the lumbar spine that, in turn, lead to the early development of degenerative

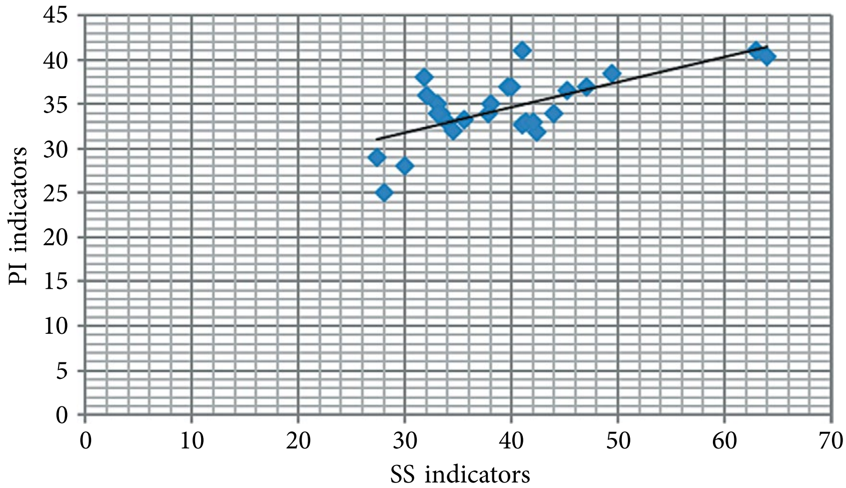



**Fig. 4.** Strong correlation between PI (pelvic incidence) and SS (sacral slope) values in the study group after treatment ($r = 0.67$; $p < 0.05$)

processes in the anterior or posterior supporting complex [20, 22, 23].

Data on a comprehensive preoperative examination of patients revealed abnormalities in the affected hip joint in both groups of patients. Such abnormalities are characteristic of dysplastic hip subluxation. These changes were manifested both in the clinical picture of the disease (pain syndrome, claudication, and limitation of in the hip joint movement), and in the data from radiological examinations in the form of pathological spatial orientation and disruption of the ratios between pelvic and femoral joint components. In addition, both groups showed lumbar spine hyperlordosis and disruption of sagittal vertebral-pelvic ratios (negative global sagittal balance and excessive pelvis anteversion). The literature analysis showed that only one publication described the state of sagittal vertebral-pelvic ratios in adults with hip dysplasia. The results of the studies conducted by a group of Japanese scientists who evaluated the vertebral-pelvic ratios in children with this pathology are almost identical to our preoperational data for both groups [24]. Thus, we can conclude that there are typical ratio patterns in the pelvis-spine system in the form of excessive pelvis anteversion and lumbar spine hyperlordosis.

The lack of information in the literature on the state of sagittal vertebral-pelvic ratios in children with dysplastic instability of the hip joints after a triple pelvic osteotomy precludes the possibility of a comparative analysis of our data. At the same time, it should be noted that excessive pelvis anteversion (increased SS) and lumbar spine hyperlordosis after restoration of hip joint stability was preserved only in the control group, which was a cardinal difference from the results of the study group. These disorders, according to the literature, are a direct prerequisite for the early development of degenerative-dystrophic changes in the posterior supporting complex or spondylolisthesis [25, 26]. Thus, the improved surgical technique for the triple pelvic osteotomy significantly improved the sagittal vertebral-pelvic ratios and eliminated lumbar spine hyperlordosis. Considering the literature on the state of sagittal vertebral-pelvic ratios in healthy children and adults [13, 14] and the significance of the only anatomical index, the PI index, we conclude that the improved technique of pelvic osteotomy directly reduces the PI value.

Actively developing 3D-modeling and prototyping technologies allows us to expand the use of personalized navigation patterns. The overwhelming majority of authors report a significant increase in the accuracy of surgical interventions that improve the results of treatment of children with various orthopedic pathologies [27, 28]. The literature contains anecdotal information on the use of navigation patterns when performing periacetabular pelvic osteotomy (cadaver study) and in the surgical treatment of posterior pelvic column fractures [29, 30]. Personalized navigation patterns make it possible to perform an exact multiplane correction of the acetabulum position when performing an improved triple pelvic osteotomy. This correction is confirmed by the data from radiological examinations. In addition to achieving an adequate correction of the dysplastic acetabular position and stability of the hip joint, triple pelvic osteotomy provided significant changes in the sagittal vertebral-pelvic ratios ($p < 0.05$) in the form of a decrease in the values of the anatomical PI index and, consequently, the SS index in the patients from the study group who received surgical treatment using the improved method. This method created the conditions for a reduction in excessive pelvis anteversion. Given the sacrum inclination angle strongly correlated with the radiological indices of the lumbar spine in all the patients from the study group, the indicators of these patients approached the average statistical normal values for this age [31]. As a result of the surgical intervention, X-ray values for the sagittal vertebral-pelvic ratios began to correspond to types II–III of vertical posture according to P. Roussoly's classification (2003). These values are considered to comprise a harmonious profile and to provide the conditions for the prevention of early development of lumbar spine osteochondrosis in this category of patients.

## Conclusion

The improved technique of reorienting triple pelvic osteotomy using personalized navigation patterns allows for a highly accurate multiplane acetabulum correction, which ensures not only the reconstruction of the acetabular component and the stability of the hip joint, but also the restoration of the sagittal profile of the spine ($p < 0.05$) with the formation of a harmonious vertical posture. The results of our study indicate the need to include a specialized in-depth X-ray examination of children with dysplastic hip subluxation in preoperative planning to assess the state of sagittal pelvic balance.

## Additional information

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**Ethical review.** The study was discussed and approved by the ethical committee of the Turner Scientific Research Institute for Children's Orthopedics under the Ministry of Health of Russia (protocol No. 2017/6 of November 28, 2017). Patients and their representatives gave informed consent to the participation in the study and publishing their personal data.

**Contribution of the authors**

*P.I. Bortulev* developed the design of the research, wrote all the paragraphs of the article, collected analyzed data, analyzed literature sources, and provided surgical treatment to the patients.

*S.V. Vissarionov* developed the research methodology, formulated the aim, edited the text of the article step by step.

*V.E. Baskov* edited article step by step, and provided surgical treatment to the patients.

*D.B. Barsukov* collected data, and provided surgical treatment to the patients.

*I.Yu. Pozdnikin* collected data, and provided surgical treatment to the patients.

*M.S. Poznovich* made 3D-modeling and prototyping.

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