MEDIUM-TERM OUTCOMES OF EXTRAARTICULAR CORRECTIVE OSTEOTOMY FOR SLIPPED CAPITAL FEMORAL EPIPHYSIS

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Despite the diversity of surgical options for slipped capital femoral epiphysis (SCFE), there is an ongoing search for the technique that would ensure a satisfactory outcome, stable fixation of bone fragments and a low rate of complications. The aim of this study was to improve the surgical technique for SCFE in patients with moderate and severe SCFE. The study included 52 children (16 girls and 36 boys) aged 10–15 years (the mean age was 13.2 years) with chronic severe (Krechmar's stage III) stable (according to Loder's classification) SCFE. The control group (n = 16) underwent a classic Imhauser procedure; the main group (n = 36) underwent a triplane osteotomy proposed by the authors of the study. The patients were examined prior to surgery and in the late follow-up period (the mean follow-up time was 4.7 years, ranging from 1 to 10 years). The procedure included a clinical examination, history taking, radiography to measure the slip angle and the severity of the slip, and the Harris hip score to assess hip function. After 4.7 years, both groups demonstrated an increase in the range of motion, in comparison with their preoperative results ($p \leq 0.05$), good Harris hip scores (94 points in the main group and 81 points in the control group. Postoperative radiographs showed consolidation of the bone, recovery of the proximal femur anatomy. Leg length discrepancy improved significantly in both groups. The proposed technique for extraarticular osteotomy allows recovering the length of the affected leg, the anatomy and physiology of the hip joint, is simple and less traumatic.

Keywords: slipped capital femoral epiphysis, corrective extraarticular femoral osteotomy, hip joint, Imhauser procedure

Author contribution: all authors contributed equally to the study and the manuscript, all read and approved the final version of the manuscript.

Compliance with ethical standards: the study was approved by the Ethics Committee of Pirogov Russian National Research Medical University and complied with the principles of the Declaration of Helsinki. Informed consent was obtained from the patients' parents.

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Received: 10.01.2022 **Accepted:** 24.01.2022 **Published online:** 31.01.2022

DOI: 10.24075/brsmu.2022.003

СРЕДНЕСРОЧНЫЕ РЕЗУЛЬТАТЫ ВНЕСУСТАВНОЙ КОРРИГИРУЮЩЕЙ ОСТЕОТОМИИ БЕДРА ПРИ ЮНОШЕСКОМ ЭПИФИЗЕОЛИЗЕ ГОЛОВКИ БЕДРЕННОЙ КОСТИ

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Несмотря на множество предложенных методов хирургического лечения юношеского эпифизеолиз головки бедренной кости ЮЭГБК, продолжаются поиски варианта операции, обеспечивающей удовлетворительную коррекцию, стабильную фиксацию костных фрагментов и низкий уровень осложнений. Целью работы было усовершенствовать технику лечения пациентов с ЮЭГБК средне-тяжелой степени. В исследование вошли 52 ребенка в возрасте 10–15 лет (средний возраст 13,1), из них 16 девочек и 36 мальчиков, страдающие ЮЭГБК тяжелой степени (3-я стадия по классификации Кречмара), хронического течения, стабильного типа (классификация Loder). Пациентам контрольной группы (n = 16) выполнена стандартная операция по Imhauser, исследуемой (n = 36) — авторская трехплоскостная остеотомия. Пациентов обследовали до операции и в отдаленные сроки (средний срок наблюдения составил 4,7 года (от 1 до 10 лет) с помощью клинического метода (сбор анамнеза, объективное исследование), рентгенологического метода (определение степени соскальзывания и угла соскальзывания), а также опросника функционального состояния (Harris hip score). В среднем через 4,7 года в обеих группах отмечено увеличение объема движений в сравнении с дооперационными показателями ($p \leq 0{,}05$), хорошие функциональные показатели HHS (в исследуемой группе — 94 балла, в контрольной — 81 балл); на контрольных рентгенограммах отмечена консолидация костных фрагментов с сохранением коррекции проксимального отдела бедра, длина конечностей также восстановилась в обеих группах. Предложенная внесуставная остеотомия позволяет восстановить длину конечности, анатомо-физиологические взаимоотношения в тазобедренном суставе, проста в исполнении и менее травматична.

Ключевые слова: юношеский эпифизеолиз головки бедренной кости, внесуставная корригирующая остеотомия бедра, тазобедренный сустав, операция Imhauser

Вклад авторов: все авторы внесли существенный вклад в проведение исследования и подготовку статьи, прочли и одобрили финальную версию перед публикацией.

Соблюдение этических стандартов: исследование одобрено этическим комитетом РНИМУ им. Н. И. Пирогова (протокол № 213 от 13 декабря 2021 г.) выполнено в соответствии с этическими стандартами Хельсинской декларации; родители пациентов дали согласие на обработку и публикацию их персональных данных.

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Статья получена: 10.01.2022 **Статья принята к печати:** 24.01.2022 **Опубликована онлайн:** 31.01.2022

DOI: 10.24075/vrgmu.2022.003

Slipped capital femoral epiphysis (SCFE) is a relatively rare, predominantly juvenile disorder [1]. Due to a variety of causes, including endocrine, the osseous tissue of the metaphysis at the epiphyseal-metaphyseal junction undergoes structural transformation resulting in the disruption of the osteoclast/osteoblast balance and accompanied by the spatial arrangement of the extracellular elements of connective tissue. The bone resorbs, and the epiphysis slips out of its normal position [2, 3]. The typical underlying mechanism of SCFE is associated with high axial load and is characterized by the posterior-inferior displacement of the epiphysis and its retroversion [4].

The disease occurs in 4–5 individuals per 100,000 population. It is more likely to affect pubescent boys aged 12–13 years (the male to female ratio is 3 : 2). Clinically, it presents as outer thigh pain or pain in the hip and knee joints (as a rule, pain in the knee joint is more common), which often urges the doctor to search for a possible knee joint pathology and thus misdiagnose the patient, because the true cause of pain, i.e. slipped proximal femoral epiphysis, remains overlooked.

There are a few classifications of SCFE used in clinical practice. The Southwick Slip Angle Classification is based on the epiphyseal-metaphyseal angle and categorizes the degree of epiphyseal displacement as mild (0–30°), moderate (30°–50°) and severe (> 50°). The Loder Classification evaluates epiphyseal stability and the patient's ability to bear weight. A stable slip means that the patient is able to bear weight with or without crutches; an unstable slip means that the patient is unable to bear weight even with crutches.

Another classification was proposed by Krechmar in 1982:

Stage I: predisplacement; no signs of epiphyseal displacement, pronounced changes in the proximal physis (growth plate) and the metaphysis (femoral neck);

Stage II: the epiphysis is displaced posteriorly (≤ 30°) and inferiorly (≤ 15°); there are structural changes in the metaphysis; the proximal physis is open;

Stage III: the epiphysis is displaced posteriorly (> 30°) and inferiorly (> 15°); there are structural changes in the metaphysis; the physis is open;

Stage IV: acute posteroinferior displacement of the epiphysis; the physis is open;

Stage V: residual proximal femoral deformity with various degrees of epiphyseal displacement and the closed proximal physis.

This grading system integrates some of the abovementioned classifications and is, in our opinion, the most convenient.

On examination, patients with SCFE have a limp, the affected leg appears shorter, there is excessive external rotation of the hip, progressing over time; internal rotation of the hip is limited; reaching the full range of motion is painful. Krechmar's stage III is characterized by the positive Hofmeister-Drehmann's sign. The diagnosis is confirmed by anteroposterior and frog-leg lateral radiographs. In 20% of cases, SCFE is bilateral [5].

Because the condition is rare, it is often diagnosed in the advanced stage. In the majority of cases, patients with SCFE are hospitalized when the proximal femur deformity becomes very pronounced [1]. SCFE has a serious social impact, so it is important to ensure prophylaxis of early hip joint osteoarthritis, hip impingement syndrome and avascular necrosis of the epiphysis, which has been correlated with SCFE in a number of studies [6, 7].

The main goal of SCFE treatment is to prevent further femoral deformation, stabilize the proximal epiphysis and preserve blood supply to the epiphysis [8].

A diversity of surgical interventions for chronic SCFE have been proposed, including *in situ* fixation with pins, screws or plates, epiphysiodesis and various types of proximal femur osteotomy [9].

At present, the preferred treatment option for moderate and severe epiphyseal displacement (> 30°) is osteotomy [10]. Depending on its site, osteotomy can be classified into subcapital (the Dunn procedure, Fish cuneiform osteotomy), osteotomy conducted at the femoral neck base (Kramer intraarticular osteotomy Badama extraarticular osteotomy) and intertrochanteric (the Southwick and Imhauser procedures). The outcome is measured by assessing hip joint function, the presence of residual displacement, the adverse sequelae of the surgical intervention (impaired blood supply to the femoral head), and the simplicity of the surgical technique [11].

In theory, proximal osteotomies of the femoral neck (Dunn procedures) are the ideal tool for restoring the anatomy of the proximal femur because SCFE-related deformities arise at this particular anatomical site [12]. However, there are reports that these procedures impede blood supply to the femoral head and cause avascular necrosis of the femoral head in 10–26% of patients. Due to the high risk of avascular necrosis, it was proposed to perform osteotomy in the intertrochanteric area of the femur [13].

Southwick osteotomy is a classic surgical intervention for SCFE. It corrects the metaphyseal-diaphyseal angle and eliminates excessive external rotation of the hip; however, it does not significantly affect the position of the proximal epiphysis in the acetabulum. In the past, neither surgeons, nor patients were fully satisfied with the outcome, which gave rise to multiplane osteotomies [14].

A triplane corrective osteotomy was proposed by Krasnov AI (RU 2364365, C2). It is more pathogenetically reasonable because it simultaneously corrects deformities in the frontal, horizontal and sagittal planes; fixation is performed with an angled blade plate [15].

Among the main drawbacks of the Krasnov osteotomy are its technical difficulty and the need to cut off the greater trochanter, which results in prolonged operative time. Besides, during this type of surgery, rotation is performed according to the position of the blade, i.e. around the longitudinal axis of the metaphysis. If the epiphysis is significantly displaced posteriorly (>40°) and only slightly inferiorly, which is a common occurrence, rotation of the proximal femur around the metaphyseal axis pushes the epiphysis and the metaphysis into a valgus and varus position, respectively. This results in a hip subluxation and/or the varus deformity of the metaphysis, with the high position of the greater trochanter, leading to the dysfunction of gluteal muscles and limping [16].

There is another variant of triplane corrective osteotomy with an angled blade plate (RU 2604039, C1). Advantageously, by changing the rotational axis of the proximal femur, correction can be performed in the frontal, horizontal and sagittal planes, preventing angular deformity of the femoral diaphysis, hip subluxation and varus deformity of the metaphysis [17].

In 1966, Imhauser described an intertrochanteric osteotomy that eliminated femoral varus and metaphyseal extension and rotation. The surgery is essentially a cuneiform osteotomy involving resection of the anterior or anterolateral fragment of the bone, followed by blade plate fixation [18]. There is a wealth of publications about this procedure, indicative of its popularity. It should be noted that femoral head subluxation in the setting of excessive valgization and a deformity of the proximal femur are common complications of this intervention [19–21].

Considering all currently existing surgical treatment options, their complications, stability of epiphyseal fixation, duration of postoperative immobilization and patient outcomes, we developed an original technique for SCFE correction based on the analysis of the aforementioned procedures. The aim of this study was to improve the outcomes of SCFE treatment in children and to assess the effectiveness of the proposed technique.

METHODS

Our retrospective study included 52 children with SCFE undergoing treatment at the Children's hospital of the Department of Traumatology, Orthopedics, and Disaster Surgery

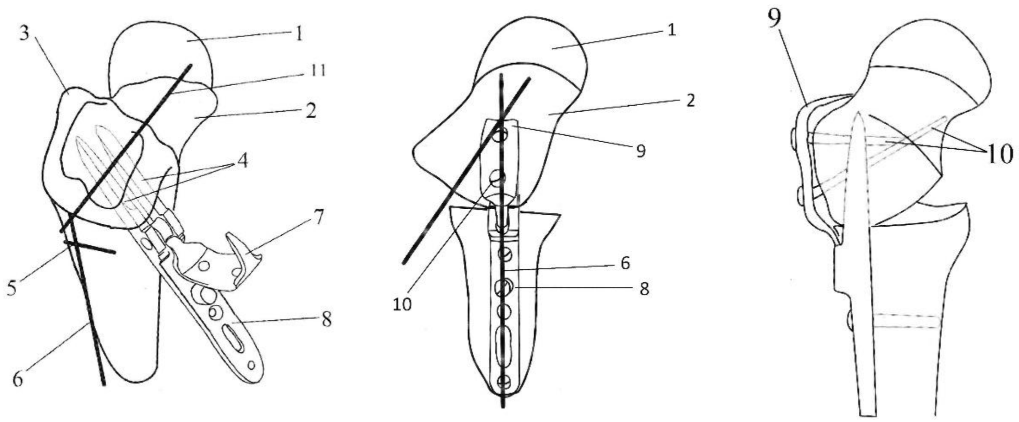

Fig. 1. The schematic representation of the proposed osteotomy technique. 1 — femoral epiphysis; 2 — femoral metaphysis; 3 — the greater trochanter; 4 — jaws of the Trotsenko–Nuzhdin plate; 5 — osteotomy site; 6 — the longitudinal axis of the femoral diaphysis; 7 — the locking part of the plate; 8 — the diaphyseal part of the plate; 9 — the part of the plate anchored to the greater trochanter; 10 — screws fixing the Trotsenko–Nuzhdin plate; 11 — the longitudinal axis of the femur

from 2010 to 2020. All patients underwent a clinical examination (medical history and complaints, demographic characteristics, symptoms, range of motion assessment) and radiography; pain and hip function were assessed using the Harris hip score [22].

The patients were divided into 2 groups. The control group included patients undergoing a classic intertrochanteric Imhauser osteotomy, the main group comprised patients undergoing the original variant of osteotomy proposed by the authors of this study [23].

The following inclusion criteria were applied: posterior (30°) and/or inferior (>15°) displacement of the proximal femoral epiphysis, the growth plate being open; no past history of hip surgery; the absence of technical errors during surgery.

Exclusion criteria: posterior displacement of the epiphysis by < 30° or > 75°; the closed growth plate; a past history of hip surgery; complete separation of the epiphysis from the metaphasis (acute slip).

The clinical examination included identification of complaints and assessment of gait, i.e. limping, the ability to ambulate, pain during ambulation, pain during movements, fixed external rotation of the affected hip; limited flexion, internal rotation and adduction of the leg.

Anteroposterior and frog-leg lateral radiographs of the hip were acquired before and after surgery and in the late follow-up period. Radiographic staging was done in accordance with Krechmar and Loder classifications [24, 25].

The main outcome measure was hip function assessment with the Harris hip score. This tool was developed to evaluate the outcomes of hip surgery. It includes 4 domains: pain, function, deformity, and range of motion. For each domain, the total score is calculated (the maximum total score is 100 points). The higher the score, the better the quality of life. The score over 90 points one year after surgery was interpreted as an excellent outcome, 80–90 points as good, 65–79 points as satisfactory, and below 65 points as unsatisfactory.

All patients were examined prior to surgery and in the late follow-up period. All patients underwent an osteotomy and were advised to unload the operated leg for 4–12 months. After 4–12 months, the plate was removed and the follow-up observation continued.

Statistical analysis was conducted in SPSS (IBM SPSS Statistics 22; USA), and Excel (Microsoft; USA). The significance of differences between the groups was assessed using the non-parametric Kruskal-Wallis test; correlations between two quantitative variables were measured using the Spearman rank correlation coefficient. Differences were considered significant at $p < 0.05$.

Surgical technique

In the proposed technique, the spatial position of the axis around which the proximal femur is rotated during femoral

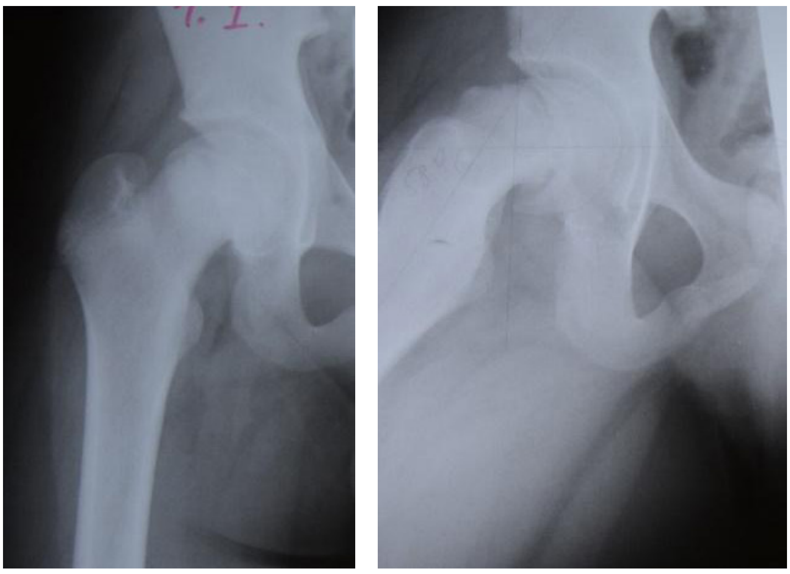

Fig. 2. The anteroposterior and frog-leg lateral radiographs of the right hip (patient M., 12 years). Stage III chronic SCFE

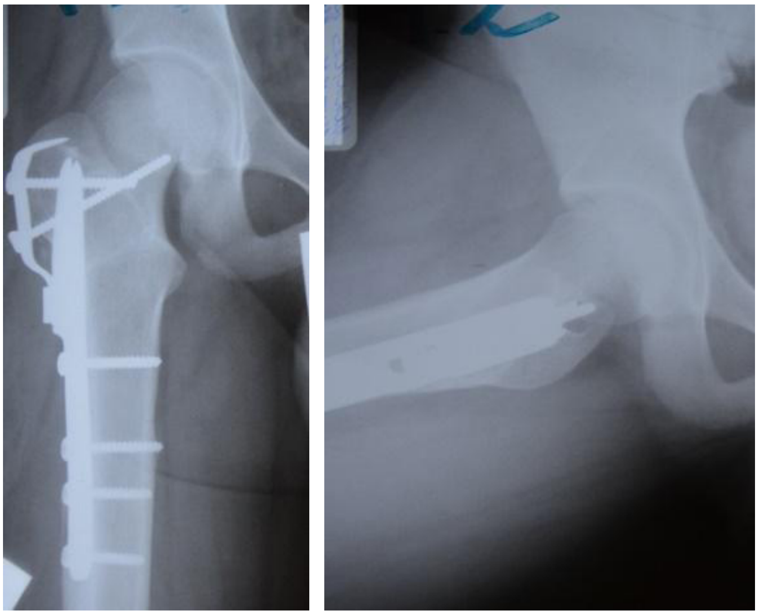

Fig. 3. The anteroposterior and frog-leg lateral radiographs of the right hip (patient M., 12 years) after an intertrochanteric osteotomy of the hip with plate fixation

osteotomy is different, as is the osteotomy type (Fig. 1). Fixation is performed with a Trotsenko–Nuzhdin plate. The points of entry for the jaws were planned 0.3–0.5 cm superoir to the greater trochanter growth plate and at the posterior epiphyseal displacement distance from the midline of the lateral face of the greater trochanter. The jaws of the plate must be inserted so that the angle between the line parallel to the axis of the diaphyseal part of the plate and the line parallel to the femoral diaphysis equals the angle of epiphyseal retroversion. Blade insertion channels were formed in the proximal femur. Then, high intertrochanteric osteotomy was performed and the jaws were introduced in the prepared channels. The diaphyseal part of the plate was pulled posteriorly, keeping some space between the diaphysis and the diaphyseal part of the plate, until the midlines going through the central axis of the plate and the femoral diaphysis coincided. Thus, the femoral head was recovered from its retroverted position and derotated. Then the diaphyseal part of the plate was pressed to the femoral diaphysis and the inferior displacement of the epiphysis was eliminated. The locking part of the plate was anchored to the greater trochanter; the screws were inserted in such a way that they passed outside the femoral neck. The diaphyseal part of the plate was anchored to the femur. Importantly, the maximum angle of forward rotation of the proximal femoral fragment should be 45°; rotation of over 45° is prohibited due to the risk of ischemic complications. If the epiphysis was displaced posteriorly by over 45°, residual displacement was corrected by derotating the proximal fragment, using the formula: MEA — 45° (where MEA is a metaphyseal-epiphyseal angle before surgery). If the epiphysis was displaced inferiorly, its position was corrected by valgization of the proximal fragment. To fix the Trotsenko-Nuzhdin plate, the jaws were introduced into the greater trochanter; this saves the femoral neck from injuring and helps to preserve blood supply to the proximal femur.

Postoperative rehabilitation

Postoperative rehabilitation was different in the main and control groups. In the main group, the patients remained on bed rest for 6 months and wore an antirotation foot support. The control group remained on bed rest for 3 months after surgery and wore a spica cast. Verticalization was encouraged

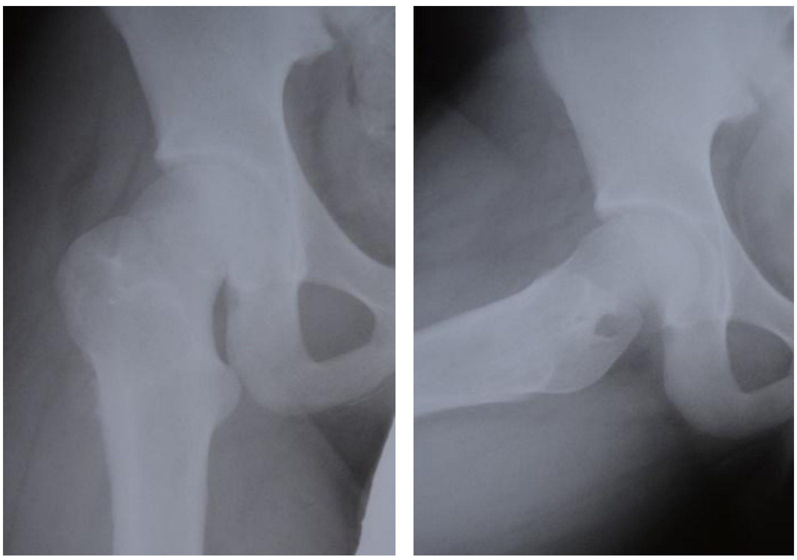

Fig. 4. The anteroposterior and frog-leg lateral radiographs of the right hip (patient M., 12 years) 12 months after the osteotomy (after bone consolidation and plate removal)

Table. Dynamics of leg length discrepancy 4.7 years after surgery

Group	Preoperative leg length discrepancy, cm		Postoperative leg length discrepancy, cm	
	Me	Q_1–Q_3	Me	Q_1–Q_3
Main	1.25	0.63–2	0	0–05
Control	1	0.5–1.38	1	0.5–1

at week 6 in the main group and at week 3 in the control group. Early rehabilitation was carried out only in the control group and included passive and, later, active physical exercise.

The plate was removed 10–12 months after the intervention.

RESULTS

A total of 52 patients were included in the study. Of them, 16 (30.8%) were girls and 36 (69.2%) were boys. The main group comprised 36 patients and the control group consisted of 16 patients. All patients were 10–15 years old; the mean age was 13 ± 1.1 years.

In the main group, there were 12 girls (33.4%) and 24 boys (66.6%); the control group included 4 girls (25%) and 12 (75%). The mean age in the main group was 13 ± 1.1 years ($p = 0.1$).

In both groups, all patients (100%) presented with pain and gait disturbance. All of them had a positive Hofmeister-Drehmann sign on examination.

In all patients, a positional deformity was observed in one of the legs due to excessive external rotation. For external rotation, the postoperative range of motion was 41.2° on average (40.8° in the main and 42.2° in the control groups, respectively; $p = 0.3$). Preoperatively, it was 69.0° (68.4° and 69.9° in the main and control groups, respectively; $p = 0.2$).

Internal rotation of the hip was limited in all patients; the average range of motion was 5.2° (4.8° and 6.9° in the main and control groups, respectively; $p = 0.006$). The leg length discrepancy was comparable between the groups, equaling 1.25 cm on average (1.20 cm in the main vs 1 cm in the control group; $p = 0.02$).

The metaphyseal-epiphyseal and the epiphyseal-diaphyseal angles were measured in the frog-leg lateral and the anteroposterior radiography views, respectively (Fig. 2–4). The average angle of posterior epiphyseal displacement was 46.8° (47.7° and 45.8° in the main and control groups, respectively; $p = 0.002$).

Due to the risk of acute epiphyseal slippage, the Harris hip score for hip function assessment was not used during the preoperative examination.

The average length of hospital stay was 14.4 in the main group vs 15.7 days in the control group ($p = 0.0075$). Average operative times were 71 min in the main group vs 137 min in the control group ($p = 0.0011$).

The follow-up examination performed 4.7 years (on average) after the surgical procedure revealed an improvement in internal hip rotation by an average of 16.7° (20.1° in the main group vs 9.1° in the control group; $p = 0.0024$). The leg length discrepancy was compensated and was now 0.5 cm on average (0 cm in the main group vs 1 cm in the control group; $p = 0.5$) (see Table).

Hip function assessment was performed only in the late follow-up period (4.7 years after the osteotomy), so it is impossible to track how hip function had been changing over that period, but the end result can be measured in both groups. The average Harris score in the late follow-up period was 89 points (94 points in the main group vs 81 points in the control group; $p = 0.001$) (Fig. 5).

Chondrolysis is a serious complication of surgery for SCFE and the disorder itself. Chondrolysis was observed in one patient in the main group (2.8%) and two patients in the control group (5.6%; $p = 0.0013$).

DISCUSSION

The literature offers a diversity of surgical techniques for treating chronic SCFE. The choice of the technique depends on the stage of the disorder and the experience and skills of the operating surgeon.

Today, SCFE is usually managed with intertrochanteric and subtrochanteric osteotomies of the femur involving fixation with an angled blade plate and screws or by an osteotomy of the femoral neck with screw fixation.

The original technique for metaphyseal osteotomy proposed by the authors of this study has demonstrated good outcomes and a low rate of complications.

Demographic parameters (age and sex), the average range of motion for external rotation of the hip and leg length discrepancy were comparable between the groups ($p \geq 0.05$). There was a significant difference in the range of motion for internal rotation: 4.8° in the main vs 6.9° in the control group ($p = 0.006$). The length of hospital stay was comparable, but the average operative times differed significantly, being shorter in the main group.

The follow-up examination conducted 4.7 years after the osteotomy revealed an increase in internal rotation, which was

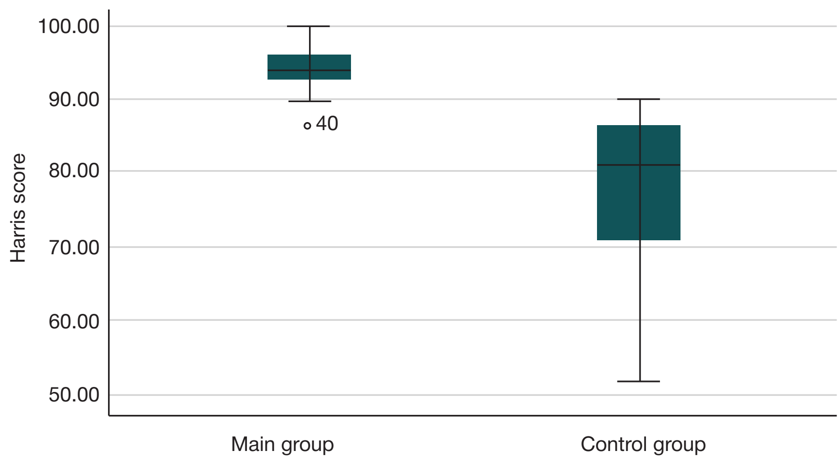

Fig. 5. Harris scores 4.7 years after surgery in the main and control groups

significant in the main group (20.1°), compared to the control group (9.1°; $p = 0.0024$).

Hip function was assessed 4.7 after the osteotomy using the Harris hip score; the average score was 94 points for the main group and 81 points for the control group ($p = 0.001$).

The analysis of the obtained data showed that the main group subjected to a triplane osteotomy and fixation with the Trotsenko-Nuzhdin blade plate tolerated the procedure better (the intervention was shorter due to its technical simplicity). The duration of postoperative immobilization with antirotation foot support was minimal in the main group, which facilitated the early commencement of rehabilitation. Consequently, most patients in the main group were able to improve internal hip rotation and restore the length of the affected leg to the maximum possible extent. Owing to the design of the Trotsenko–Nuzhdin plate (the bifurcated blade is introduced into the greater trochanter), the femoral neck was not traumatized intraoperatively, which had a positive effect on blood supply to the epiphysis.

Corrective femoral osteotomy involving correction of the proximal femur rotation axis allows recovering the proper centration of the femoral epiphysis, prevents angular deformation of the femoral diaphysis, hip subluxation and varus deformity of the metaphysis, reduces the risk of avascular necrosis of the epiphysis and articular cartilage chondrolysis, delays progression of hip arthrosis, and puts off the need for hip replacement until much later.

CONCLUSIONS

The proposed technique for corrective osteotomy of the femur in patients with stage 3 chronic SCFE prevents subluxation of the affected hip, deformity of the proximal femur and shortens rehabilitation time. The simplicity of the technique and stability of fixation result in shorter operative time, less intraoperative blood loss and make postoperative patient management less complicated.

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