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# *New method of corrective femoral osteotomy in children with slipped capital femoral epiphysis*

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**Introduction** Extra-articular corrective rotational femoral osteotomies enable to completely restore or approximate to the normal the spatial position of the femoral epiphysis and its balance with the acetabulum in patients with most common types of slippage in moderate stable slipped capital femoral epiphysis (SCFE). **Aim** Evaluation of the effectiveness of a new corrective femoral osteotomy technique that excludes hip subluxation and bayonet deformity of the proximal femur during surgery in children with SCFE. **Materials and methods** Pre- and postoperative findings of clinical and radiographic examination of 80 patients aged from 11 to 15 years with most common types of moderate stable femoral epiphyseal slippage were analyzed. The technique of corrective femoral osteotomy developed which was applied in 40 patients (40 interventions) differs in spatial position of the rotation axis of the proximal femur and type of bone cut. **Results** Subluxation and bayonet deformity of the proximal femur in the affected joint were obtained in none of the 24 cases with a maximum anterior rotation of the proximal femur fragment (45°) operated with the new technique while with the Imhauser osteotomy, previously used in group 2, they were seen in eight and 12 out of 24 cases, respectively. Average postoperative follow-up period was four years (range, 2-7 years).Clinical examination and X-ray study after this surgery showed no signs of coxarthrosis in 38 out of 40 cases after two years, and in 9 cases out of 10 after six years. **Conclusions** New method of corrective femoral osteotomy avoids hip subluxation and bayonet deformity during the surgery of the proximal femur as well as reduces (or completely avoids) lower limb residual shortening. This technique is relatively simple, shorter in time and less invasive than previous modifications. It also prevents femoroacetabular impingement in many clinical cases.

**Keywords**: hip joint, slipped capital femoral epiphysis, corrective femoral osteotomy, femoral head subluxation, femoroacetabular impingement

## INTRODUCTION

Various types of extra-articular corrective osteotomy of the femur with and without detachment of the greater trochanter have been currently used for a stable type of juvenile epiphyseolysis of the femoral head (juvenile SCFE) [1–4]. This operation enables to fully restore or bring to normal the spatial position of the epiphysis of the femoral head and the relations of the latter with the acetabulum in clinical cases characterized by the epiphysis slip of a moderate severity.

There are typical and rare types of chronic SCFE. The first one is a slip of the head posteriorly and downwards or only posteriorly, the second one is only downward posterolateral slippage (so-called "valgus" displacement) or only anterior one [5–8].

Numerous literature data and our own observations confirm that typical types of mild epiphysis slippage (not more than 30° posteriorly) do not require correction, since a slight residual deformity of the femoral component of the joint can be reduced and even completely eliminated due to its remodeling during ongoing growth [9–12]. In the cases in which this residual deformity causes femoro-acetabular impingement (FAI) at long term, it can be eliminated through a relatively small operation using arthroscopic techniques. However, in typical types of severely displaced epyphysis (more than 75° posteriorly), corrective osteotomy of the femur does not result in a sufficient correction of the relationship of the joint components without gross ischemic disorders in the joint [13–18].

Corrective osteotomy of the femur is used only in the absence of early SCFE complications such as hip joint chondrolysis and avascular necrosis of the femoral head [19–22]. In addition to the ongoing SCFE, this intervention is used in stable and unstable types of the disease in deformity of the femoral component of the joint.

All current modifications of the corrective osteotomy of the femur, used for displacement of the epiphysis of the femoral head posteriorly downward or only posteriorly, include the rotational (anterior rotation) component. In the Turner Institute, the methods of corrective osteotomy of the hip with an anterior rotational component have been used for several decades. In particular, A.N. Krechmar and

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A.I. Krasnov's operations were used that include the cutting off of the greater trochanter [5, 23–25]. These interventions yielded mostly good results, but were difficult to perform, time consuming and traumatic, as they include two cuts of the femur. Later, they were replaced by the Imhauser operation with an excision of the anterior or anterolateral wedge in the intertrochanteric region of the femur and fixation of the fragments with an angular plate or Yu.I. Pozdnikin's fixator.

It should be noted that in some cases of applying the above-mentioned surgical methods, when the proximal fragment was rotated anteriorly to an angle close to 45°, especially in combination with an increase in the neck-to-shaft angle (NSA), a subluxation of the femoral head occurred (**Fig. 1**). To eliminate the latter, it was necessary to reduce the NSA created, which resulted in a varus deformity of the femoral neck of varying severity with a high position of the greater trochanter and an additional shortening of the limb. In other cases, it was necessary to significantly increase the angle of anteversion of the femoral neck (FNA) during the operation, which led to the appearance of a bayonet deformity of the proximal femur (**Fig. 2**), which creates significant technical difficulties in subsequent total hip replacement, which some patients will require at long term [26–29]. These circumstances stimulated us to develop a new method of corrective osteotomy of the femur.

The **purpose** of the study was to evaluate the effectiveness of a new method of corrective osteotomy of the femur, which excludes subluxation in the affected joint and a bayonet deformity of the proximal femur during the operation for juvenile SCFE.

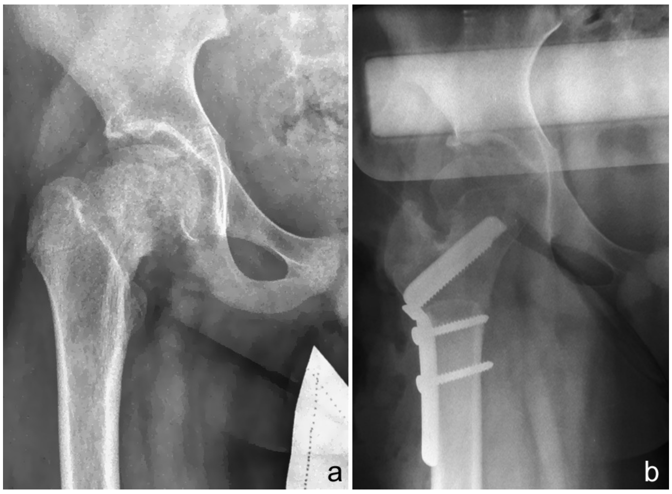


**Fig. 1** Subluxation of the femoral head, obtained during the Imhauser operation. Anteroposterior radiographs of the right hip joint of patient L., 11 years and 8 months old. Diagnosis: juvenile epiphyseolysis of the femoral head (grade 3, right hip and grade 1, left hip): **a** – before operation; **b** – during operation after preliminary fixation of fragments

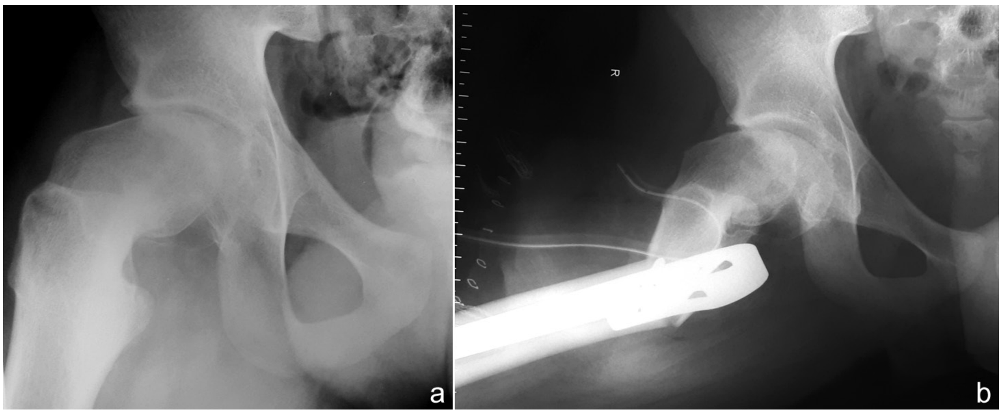


**Fig. 2** Bayonet-like deformity of the proximal femur obtained after the Imhauser operation. Radiographs of the right hip joint in the Lauenstein projection in patient R., 14 years and 9 months old. Diagnosis: juvenile epiphyseolysis of the femoral head (grade 3 on the right and grade 1 on the left): **a** – before operation; **b** – immediately after surgery

## MATERIAL AND METHODS

Since 2011, corrective osteotomy of the femur was performed according to the method developed by us (RF Patent No. 2604039, authors: I.Yu. Pozdnikin, D. Barsukov "Method of corrective osteotomy of the femur in juvenile epiphysiolysis of the femur" dated 10.12.2016) at the Turner institute in children with SCFE, characterized by displacement of the epiphysis in the posterior downward direction or only posterior one [30]. Its effectiveness is the subject of this study.

The study was conducted in accordance with the ethical standards of the Helsinki Declaration of the World Medical Association, as amended by the Ministry of Health of the Russian Federation, and approved by the ethics committee of the Turner Institute of the Ministry of Health of the Russian Federation. All patients signed informed consents for publication of data without personal identification.

We used A.N. Krechmar's classification (1982) [5], according to which the SCFE course is divided into 4 stages and there is a fifth stage which is the outcome. At stage 1 of the disease, the displacement of the epiphysis is absent; the next two stages are chronic displacement. Posterior displacement of no more than 30° refers to the second and more than 30° to the third stage.

To simplify the assessment of the effectiveness of our new method of corrective osteotomy of the femur, only those patients were analyzed who had SCFE stage 3 on one side and stage 1 on the other (40 children, group 1). They underwent anterior rotational (27 operations, 67.5 %) or rotational valgization (13 operations, 32.5 %) osteotomy of the hip on one side, and on the other one, fixation of the epiphysis of the femoral head with a screw. Results of their treatment were compared with the results of 40 more patients (group 2) with the same combination of stages of the disease that had been treated until 2011, who underwent an operation of the Imhauser type on one side (29 cases or 72.5 %, without an increase in NSA and 11 or 27.5 % with an increase in NSA), and fixation of the epiphysis of the femoral head with a screw on the other side. Those 80 children (43 boys and 37 girls) at the time of intervention were between 11 and 15 years old and at the time of comparison had the outcome stage of the disease on both sides, that is, complete synostosis at the level of the epiphyseal growth plate.

Anatomo-fuctional severity of hip disorders in pre- and postoperative period was assessed with clinical and radiographic methods. Multispiral CT was used for surgical planning.

Indication for corrective osteotomy of the femur performed with the method developed by us was stable SCFE with a typical epiphysis slippage of moderate severity: a) posterior, more than 30° but not more than 75°, with displacement downward (anterorotational or rotational valgus); b) posterior, more than 30° but not more than 75°, no displacement downward (anterorotational). Contraindication to the operation was: a) unstable SCFE; b) stable SCFE with typical types of the epiphysis slippage of mild (not more than 30° posterior) or severe (more than 75° posterior); c) stable SCFE with rare types of displacement, and also d) early complications of the disease, mentioned above. Imhauser-like operation, performed until 2011, had the same indications and contraindications.

It is important to note that corrective osteotomy of the femur was performed without prior fixation of the epiphysis of the femoral head in all clinical cases, and no postoperative progression of displacement was observed in any of the cases.

The method of performing anterorotational and rotational valgus osteotomy of the femur developed by us differs mainly in the spatial position of the rotation axis of the proximal fragment of the femur and in the nature of the bone cut performed (**Fig. 3**). An angular plate without medial bending or an LCP plate was used for fixation of fragments during the intervention.

Unlike with the methods previously used, the blade of the angular plate (or cervical LCP plate screws) was inserted into the femur not from the lateral but from the anterolateral, and sometimes, from the anterior surface of the neck, and, what is most important, not along the axis of the neck but strictly in the direction of the center of the displaced epiphysis. As a result, the axis of rotation, and, consequently, the direction of rotation of the proximal femoral fragment changed, and subluxation of the femoral head was thus avoided, even in the situations in which the rotation of the fragment anteriorly to an angle close to 45° was associated with an increase in NSA.

In all the cases, one high (intertrochanteric) and strictly transverse cut of the femur was performed. So, the process of osteosynthesis of the fragments after moving them to the position of correction was much simpler without any additional shortening of the limb. The introduction of fixating elements into the femur from the anterolateral or from the anterior surface of the neck enabled to produce a higher cut, as compared with the known methods. Such a high cut enabled to avoid a bayonet-like deformity of the proximal femur, if a significant increase in AVA was necessary. After osteosynthesis, the anterior wedge-like diastasis between the fragments was filled with an appropriately shaped autologous graft, obtained by resection of the protruding posterior part of the proximal fragment.

Studying the literature and based on our own long-term observations, we came to the conclusion that it would be inappropriate to rotate the proximal fragment of the femur anteriorly to more than 45° due to an increasing number of ischemic complications. From this it follows that a complete correction of the position of the epiphysis is possible in cases of posterior displacement of the epiphysis from 31° to 45°, and in cases of displacement from 46° to 75°, only a partial one, but residual displacement will not exceed 30°. As a result of the refusal to rotate the proximal fragment of the femur anteriorly to more than 45°, the need for cutting off the greater trochanter was no longer necessary.

NSA was increased only in rotational valgus osteotomy of the femur, while the AVA was increased in both types of intervention. For decompression of the affected joint, the tendon of the iliopsoas muscle was always cut off from the lesser trochanter during the operation. In some cases, for the same purpose, prior to osteosynthesis, the femur was shortened by 1.0–1.5 cm at the expense of the distal fragment.

Surgery was planned using computer software that creates a 3D model of the reconstructed hip joint based on the multispiral computed tomography. 3D-polymer template was printed, which was superimposed on the femur during the operation in order to more accurately and quickly insert the fixation elements into the neck and determine the osteotomy site, which significantly reduced the likelihood of technical errors and shortened the time of intervention (**Fig. 4**).

Statistical methods were used including the arithmetic mean (M), the average error of the mean (m), and the determination of the parametric Student's t-test. Statistical significance of differences in average values was determined in accordance with the table of critical values of t-test, depending on the sample size. The critical level of significance when testing statistical hypotheses was assumed to be 95 % ($p \leqslant 0.05$).

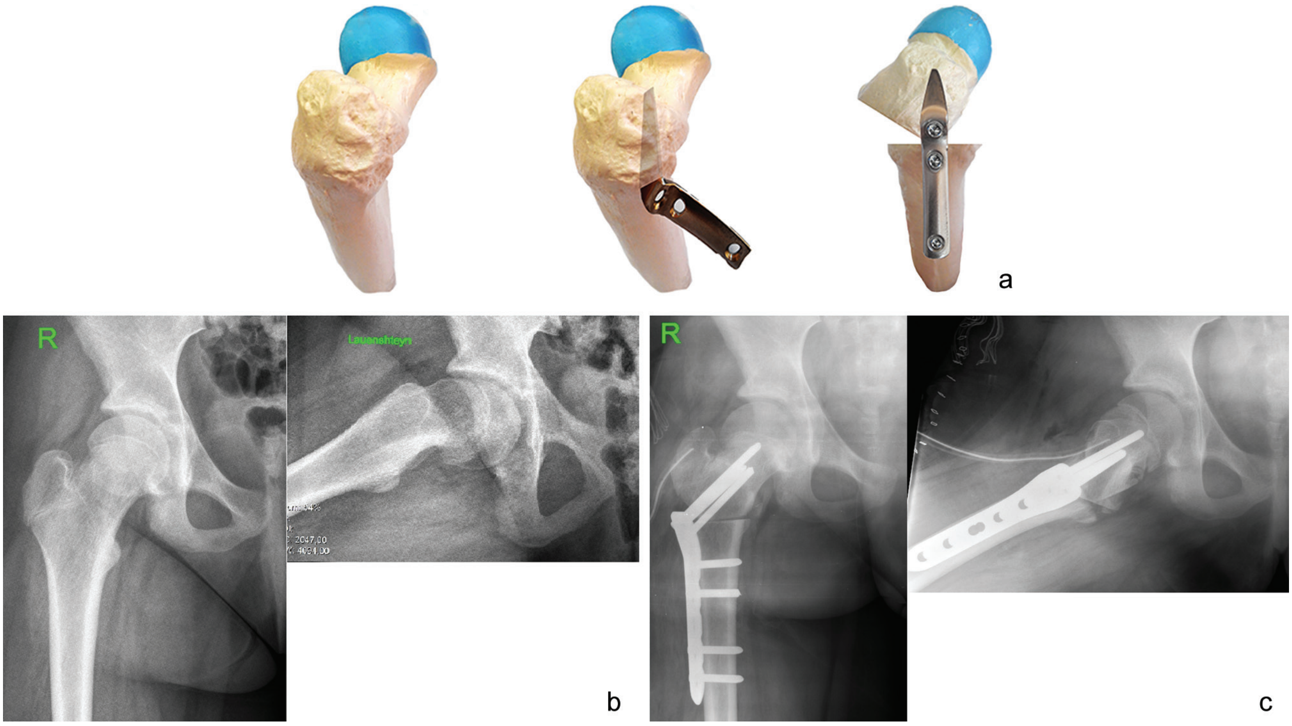


**Fig. 3** Method of anterior rotational osteotomy of the hip developed. Simulation of surgery on the model of the right femur (**a**). Radiographs of the right hip joint in the anteroposterior and Lauenstein projections in patient R., 11 years and 8 months old, with. juvenile epiphysiolysis of the femoral head in stage 3 on the right and stage 1 on the left: **b** – before surgery; **c** – immediately after surgery. Explanation in the text

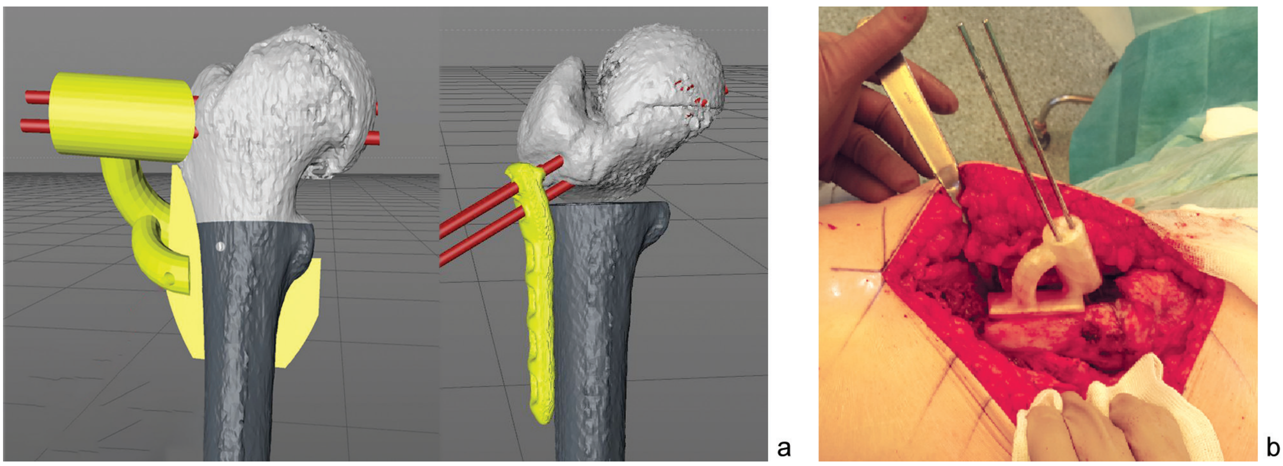

**Fig. 4** 3D-model of the hip joint reconstruction based on multispiral computed tomography (**a**); polymer template on the femur during surgery (**b**)

RESULTS AND DISCUSSION

A preoperative clinical examination was conducted with the patients only in the horizontal position and without an impingement test due to the high risk of acute displacement of the epiphysis. In stage 1 of the pathological process (80 joints in patients of both groups), clinical signs of the disease were absent, the limb was in the physiological position of external rotation (average, 16.56 ± 0.62°), therefore it was possible to evaluate the clinical parameters on the opposite side to compare with the individual norm. In stage 3 of the pathological process (80 joints in patients of both groups, mal-alignment of limb external rotation was revealed in the all cases (average, 39.0 ± 1.53°). The difference in length of the lower extremities due to the relative shortening was present in all children and averaged 1.38 ± 0.06 cm. In all the cases, there was excessive amplitude of external rotation (average, 71.0 ± 1.46°) and a reduced range of femur abduction (average, 30.56 ± 1.0°). A positive symptom of Drehmann was present in all the patients. Thereby, disorder in the external rotation of the femur by its bending to 90° averaged 34.19 ± 0.96°. Hofmeister-Drehmann sign and Thomas test were negative in all the cases.

In the preoperative period, radiography of the hip joints was taken in the anteroposterior projection and in the projection of Lauenstein. In anteroposterior projection, the positon of one of the limbs was distorted due external rotation. In addition, previous radiographs of the hip joints, which were available in the majority of the patients examined, were analyzed. In stage 1 of the disease, in both projections in all children, the growth epiphyseal plate, which normally has clear contours that limit the light strip, expanded and lost clarity of these edge-forming lines which became blurred, especially the plate contour facing the metaphysis. In 26 joints (32.5 %) in the femoral neck, in close proximity to the growth cartilage, the bone structure lost its trabecular pattern. Separate and merging areas of osteoporosis were seen adjacent to the altered growth plate (leopard skin symptom). In stage 3 of the disease, 49 patients (61.3 %) had resorption of the upper medial edge of the femoral neck in the anteroposterior projection, as a result of which the upper contour acquired a convex shape.

In 21 cases (26.3 %), the periosteum detached from the epiphysis to the lesser trochanter along the lower edge of the femoral neck, and the margin looked bi-contour. However, this symptom was not long-term: after 1-3 months, these children had a bone substance between the detached periosteum and the cortical layer of the neck, and a new anatomical symptom of the disease and dislocation appeared – thickening of the lower cortical layer of the femoral neck, the semi-oval contour of which lost its elegant shape. According to our observations, the epiphysis, which normally has a crescent shape, "sets up" when it slides in the most common direction of displacement to back- and downwards behind the neck and turns around the sagittal axis, and seems as if passes through the phases of the moon, acquiring a more rounded shape. Due to the overlay of the neck and epiphysis, all the above-described structural changes in the upper part of the metaphysis were somewhat blur, although the line of the expanded epiphyseal plate was always visible.

In the projection of Lauenstein, these structural changes were traced much longer; the centers of osteoporosis, usually oblong in shape, were located parallel to the epiphyseal plate, merging with the latter. The anterosuperior edge of the neck was resorbed in 41 observations (51.3 %) and its contour became convex, while the posterior-inferior one was also resorbed, softened and seemed cut by slipping epiphysis. Bone substance also deposited between the epiphysis and the posterior surface of the neck. In 14 cases (17.5 %), a pronounced shelf-like transition of the anterior surface of the femoral neck to the head was observed, with the protruding anterior-upper edge of the neck approaching the anterior edge of the acetabulum (**Fig. 5**). In 17 joints (21.3 %), there was a diffuse bone atrophy of the femoral head, underlined by its sharper contour.

**Fig. 5** Pronounced stair-like transition of the anterior surface of the femoral neck to the head in juvenile epiphysiolysis of the femoral head in stage 3; radiograph of the left hip joint in Lauenstein projection, patient Sh., 13 years and one month old. Explanation in the text

The nature of the epiphysis displacement was assessed on the basis of the projection NSA and epiphyseal-diaphyseal angle (EDA) in the anteroposterior projection and epiphyseal angle (EA) in the Lauenstein projection. The magnitude of the posterior displacement angle was determined by the difference in EA values in a joint with stage 1 of the disease and in a joint with stage 3. The magnitude of the angle of displacement downward was determined by the difference in the values of NSA and EDA in a joint with stage 3. In joints with SCFE stage 1 (80 joints), due to the absent epiphysis displacement, the values of NSA and EDA were similar, and the EA corresponded to the age norm. In joints with stage 3 (80 joints), two types of epiphyseal dislocation were revealed: posterior downwards in 56 (70.0 %) joints and only posterior in 24 (30.0 %) joints. The average values of the estimated angles are shown in table 1.

The table shows that the mean value of the projection NSA in the joints of stage 3 was bigger than in the joints of stage 1. It is caused by wrong positioning of the limb in children with a positive Drehmann sign.

Posterior slippage of the epiphysis to more than 45° was detected in 48 joints (60.0 %). These patients had a more marked Drehmann sign.

Result of treatment in both groups of patients was evaluated retrospectively at the stage of outcome (after the onset of complete synostosis at the level of the epiphyseal growth plate) after an average of four years (range, 2 to 7 years) on the basis of clinical and radiological data. Clinical and radiological examination of children in the postoperative period during the first year was after one, six, nine and 12 months; in the next two years – once in 6 months, and further on – once a year.

X-ray examination showed that in all 56 joints (70.0 %) with SCFE grade 3, in which the epiphysis was displaced downward, it was completely eliminated. EDA in those joints corresponded to the individual norm, that is, it coincided with the NSA value in the contralateral joint with stage 1 of the disease. The posterior epiphysis slippage was completely corrected only in 32 joints (40.0 %), in which it had been no more than 45°. Thereby, the EA value in these joints also corresponded to the individual norm – the EA value in the contralateral joint. In 48 cases (60.0 %) with posterior epiphysis slippage of more than 45°, the residual displacement averaged 14.75 ± 1.44°. In all 14 joints (17.5 %) with a stair-like transition of the anterior surface of the femoral neck to the head, the deformity remained and its severity in the postoperative period was the same. Meanwhile, as a result of the correction performed, the protruding upper anterior edge of the neck was significantly shifted from the anterior rim of the acetabulum.

It should be noted that, despite all precaution measures, two joints (2.5 %) from group 1 developed avascular necrosis of the femoral head in the postoperative period, and two joints (2.5 %) from group 2 had total chondrolysis of the integumentary cartilage. Subsequently, at the age of 17 years, these patients underwent total hip arthroplasty. However, in 76 cases (95.0 %), none of the joints with stage 3 of the disease (even if there was a residual slip) showed any radiographic manifestations of coxarthrosis during the follow-up period. In particular, there were no signs of subchondral sclerosis in the femoral head, and the radiographic joint gap maintained its normal height (**Fig. 6**). Most authors [31–34] confirm the absence of arthritic changes in the joint in the first follow-up years after corrective osteotomy of the femur with a rotational component of the correction and explain the fact by a short follow-up period.

The comparison of 24 patients from group 1 and 24 patients from group 2 with stage 3 of the disease in the joint, in who the posterior epiphysis slipped to more than 45°, seems to be the most significant.

Table 1

Mean values of NSA, EDA, EA, and of epiphysis displacement angles (degrees)

| | Stage 1 | Stage 3 |
|---|---|---|
| NSA and EDA | 134.4 ± 0.72 | |
| EA | 81.0 ± 0.31 | 38.3 ± 0.16 |
| NSA | | 139.7 ± 0.83 |
| DA | | 121.3 ± 0.58 |
| Angle of downward shift of the epiphysis | | 15.8 ± 0.49 |
| Angle of backward shift of the epiphysis | | 45.9 ± 1.33 |
| Number of joints | 80 | 80 |
| Total | 160 | |

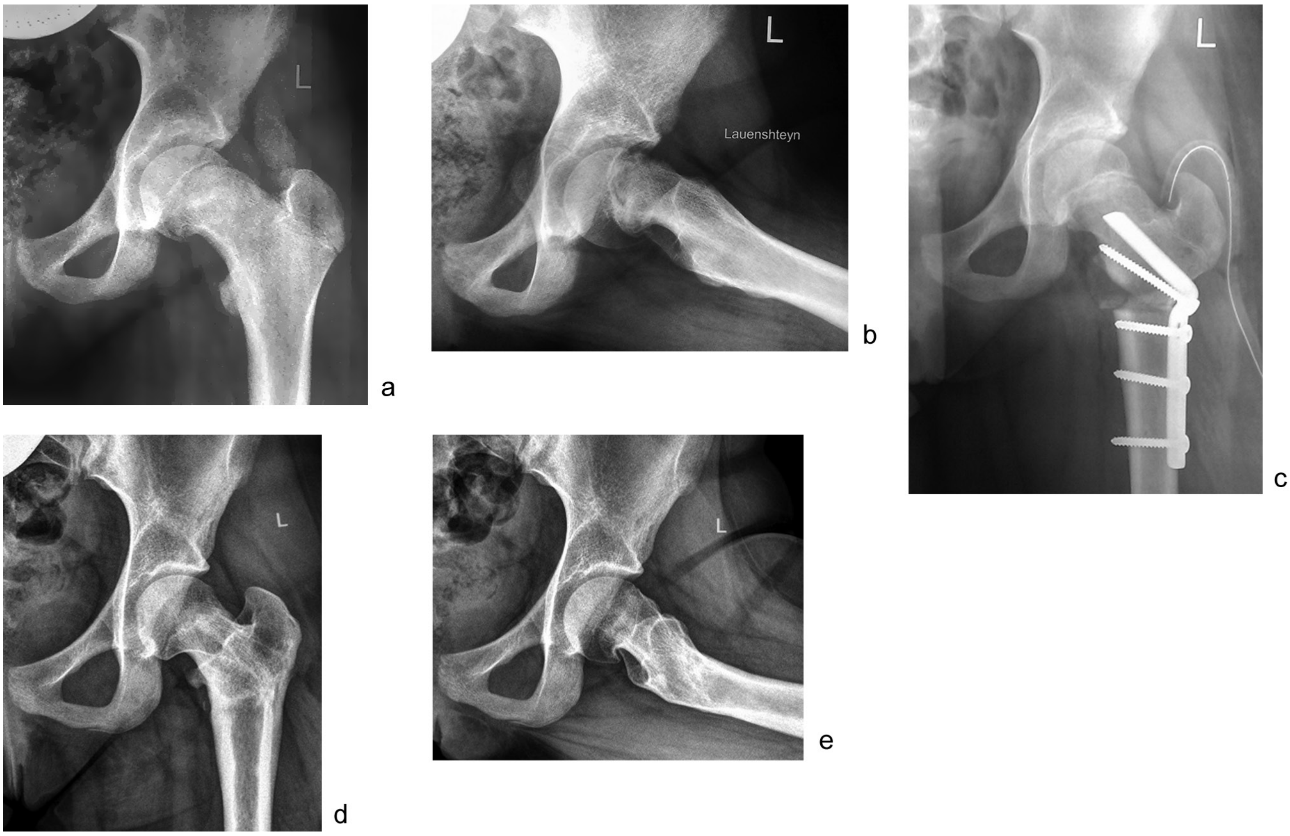


**Fig. 6** Anteroposterior radiographs of the left hip joint and in the projection of Lauenstein of patient B., 11 years and 7 months old, with juvenile epiphyseolysis of the femoral head in stage 3 on the left and stage 1on the right: **a, b** – before surgery; **c** – immediately after the operation; **d, e** – two years and 10 months after operation

Despite the maximum rotation of the proximal fragment of the femur anteriorly (45°), subluxation of the femoral head was not obtained during the operation in none of the children in group 1. Subluxation was absent even in 13 cases of rotational-valgus osteotomy of the femur, when the maximum rotation of the anterior fragment was combined with an increase in NSA. However, subluxation was detected in the joint in eight children of group 2 (33.3 %) in the radiographs, performed on the operating table after preliminary fixation of the femur fragments in the corrected position. At the same time, in six cases out of 8, in addition to the maximum rotation of the fragment anteriorly, there was an increase in NSA, and it was not changed in two cases. Subluxation of the femoral head in these patients was eliminated immediately after detection by reducing the created NSA, which led to of varus deformity of the femoral neck (average NSA, 102.63 ± 1.69°) with a high greater trochanter and additional limb shortening.

All 48 patients with posterior epiphysis slippage of more than 45° had a significant increase in NSA during the correction, so that the remaining residual displacement of the epiphysis was not manifested clinically by external rotation of the limb, which has a negative effect on gait. External rotation of the limb and the positive Drehmann sign indicate the presence of the FAI in the affected joint, and the latter, in turn, according to current literature [35–38], is the cause of early coxarthrosis. In group 2, an increase in NSA led to a bayonet-like deformity of the proximal femur in 12 children (50.0 %) with the greatest posterior slippage of the epiphysis, while in group 1 the deformity was not observed in any of the cases.

Differences detected by comparing the two groups of patients for the presence of subluxation in the operated joint and the bayonet deformity of the proximal femur were statistically significant ($p < 0.05$).

A clinical study of 76 patients (38 children from each group) who had no early SCFE complications, two years after the operation, showed that there was no or there were slight manifestations of the disease in 38 cases in group 1 (100.0 %) and in 30 cases in group 2 (79.0 %). In particular, in all these cases there was neither external rotation of the limb nor positive Drehmann sign seen in the preoperative period, and the amplitude of passive internal rotation of the femur averaged 27.1 ± 1.4° in patients of group 1 and 27.7 ± 1.7° in patients of group 2 ($p > 0.05$). Insignificant discrepancy in the length of the lower extremities (relative shortening) occurred in 18 children from group 1 (47.4 %) and in 27 children from group 2 (90.0 %) and averaged 0.75 ± 0.06 cm and 1.26 ± 0.05 cm, respectively ($p > 0.05$). In all joints, normal abduction range and negative impingement test were noted. Only six patients of group 1 (15.8 %) and five patients of group 2 (16.7 %) had a slight gait disturbance, not associated with pain. Four patients of group 1 (10.5 %) and four patients of group 2 (13.3 %) had a mild positive Duchenne-Trendelenburg sign ($p > 0.05$). However, eight cases from group 2 (21.1 %) with a varus deformity of the femoral neck, created during the operation to eliminate subluxation in the joint, had marked claudication and positive Duchenne-Trendelenburg sign. Relative shortening of the limb on the side of the deformity was observed in all these children and averaged 2.75 ± 0.25 cm. Restriction in the movements of the femur due to abduction (average, 19.38 ± 1.58°) present in all cases testified to the high position of the greater trochanter. Meanwhile, the Drehmann sign and impingement test in these patients, like in the other 68, were negative. There was no significant limitation of the amplitude of the passive internal rotation of the femur. Subsequently, the greater trochanter was brought down in five of those 8 children, and two had surgeries to equalize the length of the lower limbs.

The data of the follow-up clinical study of 20 patients (10 children from each group) out of 68 without or with minor manifestations of the disease, performed six years after the operation, corresponded to the findings of the previous studies. However, two patients aged 19 and 20 years with slipped epiphysis in the posterior downward direction (displacements in the posterior 54° and 63°) and a stair-like transition of the anterior surface of the femoral neck to the head, had periodic pain in the area of the affected joint and a positive impingement test.

## CONCLUSIONS

1. The method of corrective (antero-rotational and rotational valgization) osteotomy of the femur for managements of SCFE eliminates subluxation in the affected joint not only by maximum anterior rotation of the proximal femur (45°), but also by a combination of the maximum rotation with the increase in NSA.

2. This new method of corrective osteotomy of the femur prevents a bayonet deformity of the proximal femur, if it is necessary to significantly increase the AVA and reduce (or completely avoid) the amount of residual lower limb shortening.

3. The method of correcting osteotomy of the femur developed is characterized by a relative simplicity of performance, as well as by shorter duration and invasiveness as compared with the previously used modifications of the surgical procedure that include cutting off the greater trochanter.

4. The new method of corrective osteotomy of the femur provides prophylaxis of FAI in typical types of chronic epiphyseal slippage (posterior downwards and only to posterior) in patients with posterior slip from 31° to 45° in the absence of a stair-like junction of the anterior surface of the femoral neck to the head.

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