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Review

Correction of proximal femoral deformities in children by a guided growth technique: A review

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ABSTRACT

BACKGROUND: After surgical treatment of proximal femoral deformities in children, secondary deformities can often develop. They can be corrected successfully by epiphysiodesis — a method of working with growth zones.

AIM: To analyze the literature about the development of epiphysiodesis, a proximal femoral technique, and the results of its use in pediatric patients with hip joint pathologies.

MATERIALS AND METHODS: The results of using epiphysiodesis for treating secondary deformities in children with hip joint pathologies were analyzed. The literature search was performed in open electronic scientific databases eLibrary and PubMed for the period from 1933 to 2022.

RESULTS: Most authors reported good and satisfactory results in the correction of secondary proximal femoral deformities in children. They also suggested that the development of these deformities could be prevented by epiphysiodesis in time frames, which should be chosen correctly. However, no consensus has been established on the timing of surgical intervention and methods of its implementation.

CONCLUSIONS: Proximal femoral deformities in children, such as valgus deformity of the femoral neck and its recurrence, consequences of Kalamchi type II avascular necrosis, and hypertrophy of the greater trochanter, were corrected for a long time by a complex surgical intervention–intertrochanteric osteotomy of the femur. Improvement in examination methods and a deeper understanding of the growth zone functioning of the proximal femur allow orthopedists to introduce into practice less invasive and less traumatic but effective methods for correcting these proximal femoral deformities by controlled blocking of the growth zones.

Keywords: congenital hip dislocation; developmental dysplasia of the hip; coxa valga; Legg–Calvé–Perthes disease; avascular necrosis of the femoral head; growth plates; greater trochanteric overgrowth; epiphysiodesis; hemiepiphysiodesis.

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Научный обзор

Коррекция деформаций проксимального отдела бедра у детей методикой управляемого блокирования зон роста (обзор литературы)

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АННОТАЦИЯ

Обоснование. Деформации проксимального отдела бедренной кости у детей — одна из наиболее сложных патологий для оперативной коррекции. В большинстве случаев выполняют остеотомии бедренной кости в различных плоскостях, но в последние десятилетия появились разработки, позволяющие провести коррекцию деформации малоинвазивными способами — с использованием методики управления зонами роста проксимального отдела бедра с помощью эпифизиодеза.

Цель — проанализировать данные зарубежной и отечественной литературы, отражающие этапы развития методики эпифизиодеза зон роста проксимального отдела бедренной кости и результаты ее применения у пациентов детского возраста с патологией тазобедренного сустава.

Материалы и методы. Изучены представленные в мировой литературе результаты оперативного лечения с помощью малоинвазивной методикой эпифизиодеза зон роста проксимального отдела бедренной кости у детей. Поиск осуществляли в открытых электронных базах научной литературы eLibrary, PubMed за период с 1933 по 2022 г.

Результаты. Большинство авторов сообщают о хороших и удовлетворительных результатах коррекции деформаций проксимального отдела бедренной кости у детей, а также высказывают предположения о предупреждении развития этих деформаций путем своевременного выполнения операции эпифизиодеза. Однако единого мнения о сроках оперативного вмешательства и методах его проведения до сих пор нет.

Заключение. Деформации проксимального отдела бедренной кости у детей, такие как вальгусная деформация шейки бедренной кости и ее рецидивы, последствия аваскулярного некроза по Каламчи типа II, гипертрофия большого вертела, длительное время исправляли с помощью тяжелого оперативного вмешательства — корригирующей остеотомии бедренной кости. Совершенствование методов обследования и более глубокое понимание функционирования зон роста проксимального отдела бедренной кости позволили ортопедам внедрить в практику менее инвазивные и малотравматичные, но не менее эффективные методики коррекции данных деформаций проксимального отдела бедра путем управляемого блокирования зон роста.

Ключевые слова: врожденный вывих бедра; дисплазия тазобедренного сустава; болезнь Легга – Кальве – Пертеса; асептический некроз головки бедренной кости; гипертрофия большого вертела; эпифизиодез; гемиэпифизиодез.

Как цитировать
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BACKGROUND

Proximal femur deformities in children are commonly caused by conditions such as congenital dislocation of the femur, aseptic necrosis of the femoral head, Legg–Calve–Perthes disease, and neurogenic and other pathologies. These deformities often affect the stability of the hip joint and subluxation or dislocation of the femoral head, which impairs limb function. Corrective femoral osteotomy is performed to correct deformities, which restores the neck–diaphyseal angle and improves anteversion and centration of the femoral head in the trochanter, thus stabilizing the hip joint [1]. In some cases of progressive or recurrent deformity of the proximal femur, a single intervention is not sufficient, and repeated reconstructive surgeries are required [2]. These surgeries are technically complex, require the use of special instruments and fixation metal structures, and lead to limitations in the functional ability of the child due to cast immobilization, load restriction for 6–9 months, and movements in the joint. Furthermore, rehabilitation of such patients takes a long time, even up to a year. These limitations affect the patient's physical condition (pain, reduced range of motion, forced posture of the body and limbs) and psycho-emotional sphere by disrupting social relationships in kindergarten and school, making self-care and basic activities impossible. Therefore, orthopedic surgeons have continued to explore for minimally traumatic and invasive methods. A deeper understanding of the anatomy and physiology of the growing skeleton and on correcting deformities of the growing bones of the lower extremities by influencing the growth zones provided the impetus for applying new methods to correct proximal femoral deformities.

This study aimed to analyze data from foreign and Russian literature reflecting the stages of epiphysiodesis of the proximal femoral growth zone and its effects in pediatric patients with hip joint pathology.

MATERIALS AND METHODS

We searched and analyzed the literature for the last 70 years containing data on the technique of epiphysiodesis of the femoral neck and greater trochanter and treatment outcomes and searched for articles with similar content.

Keyword searches (developmental dysplasia of the hip, coxa valga, coxa vara, Legg–Calve–Perthes disease, congenital hip dislocation, epiphysiodesis, hemiepiphysiodesis) were performed in the open electronic databases of scientific literature eLibrary and PubMed.

RESULTS AND DISCUSSION

The first attempts to manipulate bone growth zones in children were described by Phemister in 1933 [3]. He corrected axial deformities of the lower limbs and length inequalities by open destruction of the growth plate of the femur or tibia, resulting in complete cessation of bone growth of the segment. Complete destruction of the growth zone was then called total epiphysiodesis.

Subsequently, after evaluating the advantages and disadvantages of the method, Metaizeau, Blount, and Stevens refined the technique of interaction with the growth zones. Metaizeau proposed performing total epiphysiodesis in a closed method through small incisions by inserting two transcutaneous screws [4]. Blount used metal staples to correct axial deformities in growing children, temporarily restricting bone growth with the possibility of their subsequent removal after achieving a satisfactory correction, called temporary hemiepiphysiodesis or "controlled blocking of growth zones" [5]. This technique allowed preservation of the growth zone function, and after removal of the metal constructs, growth continued similar to that of the unoperated limb.

Stevens replaced metal brackets with octagonal plates, which increased the stability of the metal structure and accelerated the correction of deformities [6].

A study by Phemister has led pediatric surgeons to experiment with other lower limb growth zones. Siffert studied the anatomical development of the hip joint and proximal femur in children and described the function of the Y-shaped cartilage (triradiate cartilage) and the growth zones of the femur (epiphysis of the femoral head, upper edge of the neck, and greater trochanter). He has found that changes in the function of one zone affected the other zones. By understanding these relationships, it is possible to predict the onset and progression of hip deformities and avoid severe surgical intervention [7–9].

Physicians have primarily identified two types of deformities that are most common in proximal femoral growth zone dysfunction: valgus deformity of the femoral neck and hypertrophy of the greater trochanter.

In 1980, Kalamchi and MacEwen evaluated 119 patients with congenital dislocation of the femur and found that damage to the lateral part of the growth zone (head) of the femoral physis leads to neck shortening and valgus deformity and that central damage has no effect on the change in the neck–diaphyseal angle; thus, they developed four types of osteonecrosis depending on the involvement of the femoral epiphysis and physis [10].

Furthermore, Campbell and Tarlow studied 146 children with dysplasia after conservative treatment and detected dysfunction and closure of the lateral part of the growth zone of the femoral head epiphysis in 14 patients and concluded that this lesion was an iatrogenic pathology caused by traumatization of the head during dislocation repair or after a period of immobilization in the limb abduction position. Premature closure of the lateral edge of the growth plate resulted in a valgus deformity of the femoral neck, shortening,

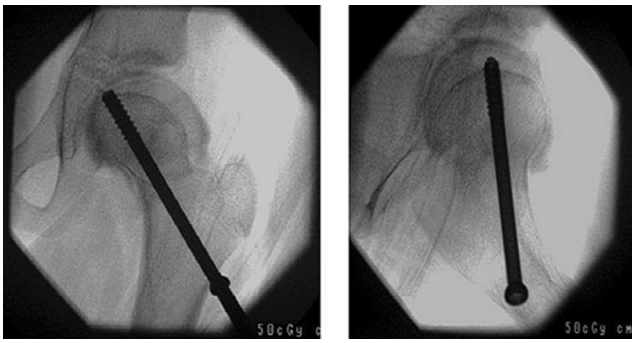

Fig. 1. Medial epiphysiodesis [24]

and displacement of the head epiphysis to the greater trochanter. The authors also observed lower extremity length inequalities of 1–5 cm caused by femoral neck shortening and excessive valgus deviation. The authors performed varus intervertebral osteotomy to correct the femoral deformity; however, some patients required revision surgery. As an experiment, a screw was placed in several patients in conjunction with an intervertebral osteotomy to cross the medial growth plate of the physis (Fig. 1), and excellent results were noted [11].

Although surgeons from different countries have performed similar operations with blocking of the medial growth zone of the femoral neck, these were experimental operations on a small number of patients [12, 13]. Animal studies have continued to clarify and expand the knowledge of femoral neck growth zone surgery [14]. In 2006, Chang et al. have shown that a screw inserted into the medial part of the femoral neck, passing through the epiphyseal plate, would cause its variation over time. The study was conducted on eight pigs because their bones are anatomically similar to human bones. The clinicians confirmed their hypothesis by obtaining a decrease in the neck–diaphyseal angle in the operated limb compared to the "healthy" limb, which was 132.8° (128–142) vs. 141.41° (136–152) [15]. The authors have further recommended correcting the torsional deformity of the femur by changing the direction of screw insertion.

In 2010, McCarthy et al. conducted a similar study in lambs and aimed to test the efficacy of femoral neck hemiepiphysiodesis. They divided the animals into two groups: those in which the screw passed through the growth plate and those in which the screw was placed below the growth plate. They performed CT scans and histologic sections. At the end of the study, the authors confirmed a satisfactory correction of the angular deformity of the femur in patients with screw penetration through the growth plate of 132° vs. 143°. However, whether the growth plates would still function if the hardware is removed was unclear. In contrast to Chang, McCarthy expressed doubts about the possibility of correcting the torsional deformity of the femur [16].

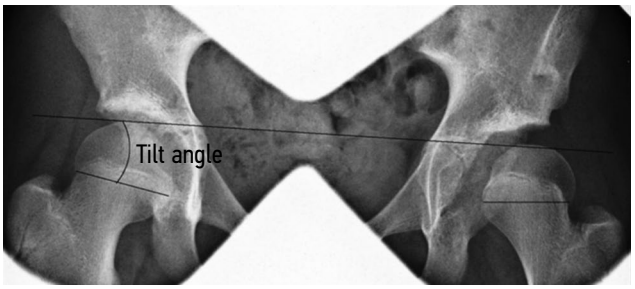

Fig. 2. Determination of the tilt angle [24]

Numerous studies on the mechanism of valgus deformity and displacement of the head epiphysis due to aseptic necrosis [17–19] did not address the issues of early diagnosis of growth zone lesions. Specialists began to use the medial hemiepiphysiodesis technique only when there was a clear radiological picture of growth zone closure and aseptic necrosis [20]; however, they did not express clear indications for when this method should be used.

In 2011. McGillion and Clarke developed additional radiological criteria to the existing ones to objectify the indications for epiphysiodesis [21–23]. They defined the following radiographic criteria to evaluate epiphyseal displacement in necrosis on anteroposterior pelvic radiographs: the angle between the Hilgenreiner line and line along the edges of the epiphysis of the femoral head. A change in the angle between these lines indicates displacement of the femoral head in relation to the pelvis, which makes it possible to suspect aseptic necrosis and deformation of the lateral growth zone over time. The authors do not give the normal values of this angle; however, note that in the norm, this angle is positive (>0), and in pathology, it decreases and the lines become parallel (Fig. 2).

This criterion is called the "tilt angle." When evaluating postoperative radiographs and following up with patients, the change in this angle allows us to assess the dynamics of the effect on the growth zone and the degree of correction of the deformity, which is what the authors presented in their study. However, they noted that the "tilt angle" is a two-dimensional analysis, whereas CT scans can assess the magnitude of anteversion in addition to the valgus deformity. CT further showed that the bony bridge of the disturbed growth zone can be located in both the posterolateral and anterolateral parts of the epiphysis of the head. Thus, the concomitant torsional deformity of the femur complicates the prediction of the efficacy of medial epiphysiodesis, and a more thorough examination of the patient is required [24].

Given the positive results of the correction of valgus deformity in hip joint pathology [25, 26], orthopedic surgeons introduced the epiphysiodesis technique in patients with infantile cerebral palsy, in whom valgization of the femoral neck is a frequent anatomical change.

Lee et al. have presented results in using medial epiphysiodesis in 13 patients. According to the results of

observations for 24–90 months (mean: 45.6 months), surgeons noted a change in the neck–diaphyseal angle after epiphysiodesis of 6.9° at 3 months, 10.6° at 1 year, and 16.1° (in three patients) at a follow-up of up to 5.8 years. However, the reduction in surgical volume and hospital stay allows the use of this technique along with soft tissue surgery. The authors have indicated that this procedure should be considered in children with fourth and fifth degrees of motor impairment [27].

In 2019, Hsieh and Portinaro confirmed the efficacy of medial epiphysiodesis in patients with cerebral palsy. Using this technique, the authors were able to prevent the progression of hip subluxation and avoid major reconstructive surgery. However, they noted migration of the screw from the head epiphysis in some patients due to continued growth; therefore, the timing of dynamic observation is crucial, and, if required, the screw should be replaced with a longer one to maintain the correction [28, 29].

The same conclusions were reached by Zakrzewski [30].

Epiphysiodesis of the femoral neck growth zone using a screw has been shown to be effective; however, its comparison with other methods of epiphysiodesis was only performed in 2016 [31]. After performing surgery on lambs, the authors compared three variants of epiphysiodesis: with a screw [16], with a plate with screws [6], and by reaming the medial growth zone with a Kirschner spoke [32]. According to the results of the study, for a follow-up period of 6.78 ± 0.45 months, in the group in which hemiepiphysiodesis was performed with a screw, a significant decrease was found in the neck–diaphyseal angle from 117 ± 1 to 100 ± 5°, whereas in the other two groups, no significant changes were noted. No statistically significant changes in the articulotrochanteric distance (ATD) were found in either group.

The authors concluded that screw epiphysiodesis is the most appropriate method to influence the medial growth zone, and the slower growth rate of the proximal femoral metaphysis compared with the distal one allows the screws to remain in the neck for much longer than in knee epiphysiodesis. However, as in a previous study [16], this method is unlikely to achieve torsional deformity correction.

The second most common deformity in proximal femoral growth zone dysfunction is hypertrophy of the greater trochanter.

In 1940, Compere et al. have created an experimental model for developing proximal femoral deformity with damage to the growth zone of the greater trochanter. After performing isolated blockage of the growth zone of the greater trochanter in goat kids, they found growth arrest and formation of *coxa valga* and *coxa plana* deformities and shortening of the greater trochanter. Additionally, the authors observed shortening of the femoral neck, which may lead to changes in the contour of the femoral head and impaired hip joint function [33].

In 1959, Laurent conducted a study on rabbits [34], which confirmed the data of Compere. He found that damage to the growth zone of the epiphysis of the head results in hypertrophy of the greater trochanter, which gradually causes insufficiency of the middle and small gluteal muscles and leads to a positive Trendelenburg and gait disturbance [35], and that isolated damage to the growth zone of the greater trochanter results in the formation of a *coxa valga* deformity with femoral neck elongation. Based on the results of the experimental studies, Laurent performed several surgical procedures with epiphysiodesis of the greater trochanter (Fig. 3) to correct progressive *coxa vara* deformity and obtained satisfactory results with improved gait.

In 1960, Edgren used radiographs to objectify the results of epiphysiodesis of the greater trochanter. Using radiographs, the author derived the ATD. If this distance decreases, the index is considered negative. Edgren compared two groups consisting of patients without pathology and those with *coxa plana* deformity. In the first group, ATD was always positive. In the *coxa plana* case series, Edgren clearly noted that premature closure of the epiphyseal plate of the femoral head was associated with decreased ATD and, consequently, hypertrophy of the greater trochanter. Edgren has revealed that gluteal muscle strength decreases in the later stages of deformity [36, 37].

In 1980, Gage and Cary have noted that epiphysiodesis of the rostral plate of the trochanter does not completely stop its growth because there is potential for growth at the expense of the apical portion (cephalic portion of the trochanter). The authors introduced the term trochanter-to-trochanter distance (TTD) to further evaluate trochanter growth. Trochanter growth was determined by measuring the TTD at follow-up and subtracting the TTD measured at surgery. The authors obtained the most favorable results when epiphysiodesis was performed in patients aged <5 years, i.e., before the appearance of the ossification nucleus of the epiphysis of the greater trochanter on radiographs. In cases of severe deformity of the *coxa vara* and significant

Fig. 3. Epiphysiodesis of the greater trochanter using a screw with a washer [54]

weakness of the gluteal muscles, surgeons recommend performing a corrective osteotomy [38].

Stevens and Coleman extended the age limit for the use of epiphysiodesis of the greater trochanter to 8 years [39], and older children were indicated to undergo transposition of the greater trochanter, as recommended by other authors [40–42]. In children aged >8 years, surgeons have recommended femoral neck lengthening surgery [43–45].

In 1989, Iwersen et al. conducted a retrospective study to evaluate hypertrophy of the greater trochanter in patients with aseptic necrosis following treatment for congenital hip dislocation. After analysis, they have noted that hypertrophy of the greater trochanter can be easily overlooked during treatment because most surgeons focus on restoring the bone–articular relationship between the head and trochanter of the hip joint, and necrosis involving the growth zone may develop much later. Patients treated under 5 years of age are less likely to have pathologic changes in ATD than older patients. While agreeing with the arguments of Stevens and Coleman, Iwersen has stated that the time to perform epiphysiodesis may be lost because of unpredictable cartilage overgrowth. Iwersen has further pointed out that the decrease in ATD on the affected side with age affects the healthy hip joint. Although this effect is not significant, further follow-up is required [46].

Matan et al. have performed a comparative analysis of two groups of patients with Legg–Calve–Perthes disease in 1996. The first group underwent varus femoral osteotomy only, whereas the second group underwent femoral osteotomy combined with prophylactic epiphysiodesis of the greater trochanter. At postoperative follow-up in the second group, the authors noted preservation of ATD, increased range of motion, decreased pain, satisfactory hip adductor strength, and increased activities of daily living. Thus, the authors confirmed their theory that the simultaneous performance of hip varus osteotomy and epiphysiodesis of the greater trochanter has a more pronounced beneficial effect [47].

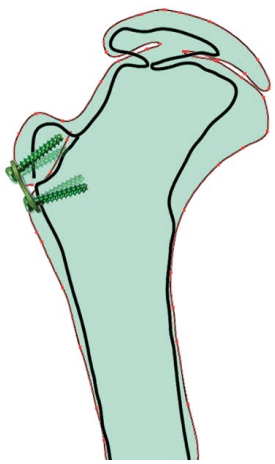

Fig. 4. Fixation of the greater trochanteric growth zone with an octagonal plate [51]

In 2008, McCarthy and Weiner [48] questioned the evaluation of ATD alone in patients with Legg–Calve–Perthes disease because the femoral head epiphysis used for measurement is affected in this pathology, which may lead to erroneous data. The authors pointed out that no alternative techniques have been proposed for performing epiphysiodesis of the trochanteric growth zone. They included 35 patients with unilateral femoral head lesions in their study. Predrilling of the greater trochanteric epiphysis followed by screw insertion was performed in 30 patients, and a bone graft was used instead of a screw in 5 patients. The authors found a 4.3 mm reduction in the growth of the greater trochanter after epiphysiodesis compared with the unaffected side. Complete closure of the greater trochanter growth zone was observed in 21 of 35 cases. Surgeons noted a more pronounced reduction in the growth of the greater trochanter in the bone graft group than in the screw group; however, the small number of patients makes it difficult to declare these data as reliably significant. Moreover, the authors observed an unexpected finding that epiphysiodesis was more effective in patients aged >8 years than in patients aged <6 years, which contradicts the data of Gage and Cary. The authors attributed these results to increased growth at older ages and easier technical performance of epiphysiodesis at this time.

In 2009, Shah et al. have revealed that epiphysiodesis of the greater trochanter during the active stage of Legg–Calve–Perthes disease reduces the incidence of hypertrophy and improves Trendelenburg test scores [49]. They found an inadequate correction in 30% of the children operated on (a total of 62 children were treated) and presented three possible reasons for this result: first, there was insufficient compression of the trochanteric growth zone with the screw during surgery; second, even with surgical disruption of the integrity of the trochanteric growth zone, growth could be preserved at the expense of the femoral neck; and third, unsuccessful surgery with inadequate correction.

Regarding age limits, surgeons obtained positive results with a negative Trendelenburg test in patients as young as 10 years, confirming the data of van Tongel [50].

Based on the findings of Langenskiold [37] that epiphysiodesis of the greater trochanter disrupts the function of its growth zone only halfway, Stevens et al. proposed a new technique for interaction with the growth plate [51]. They aimed to fix the greater trochanter not with a single screw perpendicular to the growth zone but with an octagonal plate parallel to the growth plate (Fig. 4).

The authors explained their choice of this growth zone technique by preserving more optimal femoral neck growth, which they believed could be compromised by perpendicular screw placement.

With this method of fixation (“guided growth”), the authors aimed to delay or prevent the need for transpo-

sition of the greater acetabulum and osteotomy of the femur or pelvis. According to the authors, this procedure restores the optimal length and strength of the tendons of the retracting muscles, which improves the range of motion of the hip (internal rotation and abduction); does not compromise the length of the lower limbs; and reduces lameness. After conducting a study on 12 patients aged 4–9 years, the authors determined that the most favorable age group for this surgery is 5–8 years.

According to the authors, "guided growth" of the greater trochanter corrects hypertrophy of the greater trochanter more favorably and improves adductor strength, thereby avoiding iatrogenic deformities of the proximal femur.

In 2017, Kwon et al. have analyzed the literature on the use of epiphysiodesis of the greater trochanter in Legg–Calve–Perthes disease and found that none of the authors of the studies investigated on the severity of the course of the disease. Using the classification of Stulberg, modified by Herring [52, 53], surgeons have indicated that patients with type B and borderline B/C head lesions have a more favorable prognosis for epiphysiodesis of the greater trochanter than patients with type C [54].

Comparing the results of epiphysiodesis in patients aged <8 years and those aged >8 years, the authors found that clinical and radiologic parameters were better in patients younger than 8 years. They have determined that the key factor for a satisfactory epiphysiodesis result is the 60–70° position of the screw in relation to the fibula, with the screw passing through the medial cortex.

In 2020, the surgeons of the G.I. Turner Institute analyzed the Russian literature and did not find any description of the technique of epiphysiodesis of the greater acetabular growth zone; thus, they conducted their own study to investigate the dynamics of proximal femoral growth after epiphysiodesis of the greater trochanteric growth zone and determined the possibilities of using this technique in the complex treatment of children with hip joint pathology [55]. Fixation of the greater trochanter was performed using the conventional method with a screw and washer and an octagonal plate with screws.

Surgeons noted that the severity of lameness and Trendelenburg did not increase. Partial synostosis of the metatarsal growth zone occurred within 2–4 months. Radiographic parameters showed that the effect on the growth zone of the greater trochanter slowed its growth by 49.3%. The authors concluded that the screw and washer technique is preferable because it provides faster results than using an octagonal plate, when there is a need to wait for the appearance of dynamic tension on the screws.

CONCLUSIONS

In conclusion, despite the long history of development, study, and application of the technique of blocking the growth zone of the medial part of the femoral head physis and the greater trochanter, there is still no consensus on the timing of surgical intervention and type of metal fixator (octahedral, cortical plate) and no clear data on the long-term results of interventions because of the short period of patient follow-up in the postoperative period.

Currently, medial epiphysiodesis is increasingly used in hip joint pathology and aseptic necrosis [56, 57].

The minimally invasive nature of the technique, ease of performance, rapid patient rehabilitation, and good results allow its use for correction of proximal femoral deformities and prevention of their development. However, several questions, including the possibility of correcting anteversion of the femoral neck, remain open and require further study.

ADDITIONAL INFORMATION

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All authors made a significant contribution to the research and preparation of the article and read and approved the final version before publication.

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