

Review

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# Surgical Treatment of Knee Flexion Contracture in Patients With Cerebral Palsy: A Review

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## ABSTRACT

Knee flexion contracture is the most common lower limb deformity among patients with cerebral palsy, with a prevalence of 47%–53%. Its prolonged persistence leads to marked functional impairments, such as increased energy expenditure during walking and decreased motor activity in children, and the emergence of secondary orthopedic complications, which significantly affects patients' quality of life. This review analyzed published scientific data on current surgical methods for the correction of knee flexion contracture in patients with cerebral palsy, evaluating their clinical effectiveness, determining frequency of complications, and identifying factors influencing the choice of optimal treatment strategy. The studies were determined using PubMed, Google Scholar, Cochrane Library, Crossref, and eLibrary. The search was conducted without language restrictions, covering the period from 1952 to 2024. Seventy-four sources were reviewed, including original articles and systematic reviews on surgical treatment of knee flexion contracture in patients with cerebral palsy. The primary surgical correction methods for knee flexion contracture in children with cerebral palsy are hamstring lengthening and distal femoral extension supracondylar osteotomy. Hamstring lengthening is considered the main surgical procedure and most appropriate option for patients of all age groups. Notably, femoral osteotomy has shown high clinical effectiveness in older patients, particularly in those with marked distal femoral deformities. Both methods yield favorable outcomes, but may be associated with certain complications. Furthermore, this review discusses alternative techniques, including tendon transfers and temporary hemiepiphysiodesis, and combined approaches. The conducted scientific data review confirmed the effectiveness of surgical treatment of knee flexion contracture in patients with cerebral palsy. However, in selecting a particular surgical procedure, individual anatomical and clinical features, the degree of contracture, and age-related patient characteristics should be considered.

**Keywords:** cerebral palsy; knee flexion contracture; hamstring lengthening; distal femoral extension osteotomy; crouch gait.

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# Хирургическое лечение пациентов с детским церебральным параличом со сгибательной контрактурой коленного сустава. Обзор литературы

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## АННОТАЦИЯ

Сгибательная контрактура коленного сустава занимает ведущее место среди всех деформаций нижних конечностей у пациентов с детским церебральным параличом с частотой встречаемости в 47–53% наблюдений. Длительно существующее патологическое состояние приводит к значительным функциональным нарушениям: увеличению энергозатрат при ходьбе, снижению двигательной активности ребенка и развитию вторичных ортопедических осложнений, что существенно ухудшает качество жизни пациентов. В статье проанализированы опубликованные литературные данные о современных хирургических методах коррекции сгибательной контрактуры коленного сустава у пациентов с детским церебральным параличом, а также дана оценка клинической эффективности этих методов, выявлена частота осложнений и определены факторы, влияющих на выбор оптимальной лечебной тактики. Проведен анализ публикаций из баз данных PubMed, Google Scholar, Cochrane Library, Crossref и eLibrary. Поиск проводили без ограничений по языку, охватывая период с 1952 по 2024 г. В итоговый обзор вошли 74 источника, включая оригинальные статьи и систематические обзоры, посвященные хирургическому лечению сгибательной контрактуры коленного сустава у пациентов с детским церебральным параличом. Основными методами коррекции сгибательной контрактуры коленного сустава у детей с церебральным параличом признаны удлинение сгибателей голени и корригирующая разгибательная надмыщелковая остеотомия бедренной кости. Удлинение сгибателей считают основной операцией, наиболее оптимальной для пациентов всех возрастных групп. Одновременно с этим необходимо подчеркнуть, что остеотомия бедренной кости демонстрирует высокую клиническую эффективность у пациентов старшего возраста, особенно при выраженных деформациях дистального отдела бедра. Оба подхода демонстрируют положительные результаты, однако могут сопровождаться рядом осложнений. В обзоре литературы также рассмотрены и альтернативные методы, включая пересадку сухожилий, временный гемизипсифиодез и комбинированные методики. Проведенный обзор литературы подтверждает, что хирургическое лечение сгибательной контрактуры коленного сустава у пациентов с детским церебральным параличом — это эффективный метод, однако выбор конкретного оперативного вмешательства должен основываться на индивидуальных анатомо-клинических характеристиках, выраженности контрактуры и возрастных особенностях пациента.

**Ключевые слова:** детский церебральный паралич; сгибательная контрактура коленного сустава; удлинение сгибателей голени; корригирующая надмыщелковая остеотомия бедренной кости; походка приседа.

## Как цитировать

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科学审查

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# 脑瘫患儿膝关节屈曲挛缩的外科治疗。文献综述

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## 摘要

膝关节屈曲挛缩在脑瘫患儿所有下肢畸形中占据主要地位,发生率为47%–53%。该病长期存在会导致显著的功能障碍:步行能量消耗增加、儿童运动能力下降及继发性骨科并发症,严重影响患者生活质量。本文分析了已发表的文献资料,内容涉及脑瘫患儿膝关节屈曲挛缩的现代外科矫治方法,评估了这些方法的临床疗效,指出了并发症的发生频率,并明确了影响最佳治疗策略选择的相关因素。检索PubMed、Google Scholar、Cochrane Library、Crossref和eLibrary数据库。检索时间范围为1952年至2024年,不设语言限制。最终纳入74篇文献,包括原始研究和系统综述,均涉及脑瘫患儿膝关节屈曲挛缩的外科治疗。胫骨屈肌延长术和股骨矫形性伸直型髌上截骨术被认为是脑瘫患儿膝关节屈曲挛缩的主要矫治方法。屈肌延长术被认为是主要的手术方式,最适用于各年龄段的患者。同时应强调,股骨截骨术在年长的患者中,尤其是股骨远端严重畸形者中具有较高的临床疗效。两种方法均显示出良好结果,但可能伴随一定并发症风险。文献中还分析了替代方法,包括肌腱转位、临时性半髌阻滞术及联合治疗策略。文献综述表明,脑瘫患儿膝关节屈曲挛缩的外科治疗是一种有效的方法,但具体手术方式的选择应基于患者的个体解剖和临床特点、挛缩程度及年龄特征。

**关键词:** 脑性瘫痪; 膝关节屈曲挛缩; 胫骨屈肌延长术; 股骨髌上矫形截骨术; 蹲伏步态。

## 引用本文

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## INTRODUCTION

Cerebral palsy (CP) is a group of permanent disorders of motor development and postural control caused by nonprogressive injury or abnormality of the developing fetal or neonatal brain. CP is one of the leading causes of childhood disability [1]. Epidemiological data indicate a prevalence of CP of 1.5–5.2 cases per 1000 live births [2, 3].

As children with CP grow older, their neurological condition generally improves and stabilizes. However, secondary orthopedic complications tend to develop and progress over time, leading to persistent upper and lower limb contractures and deformities (Fig. 1).

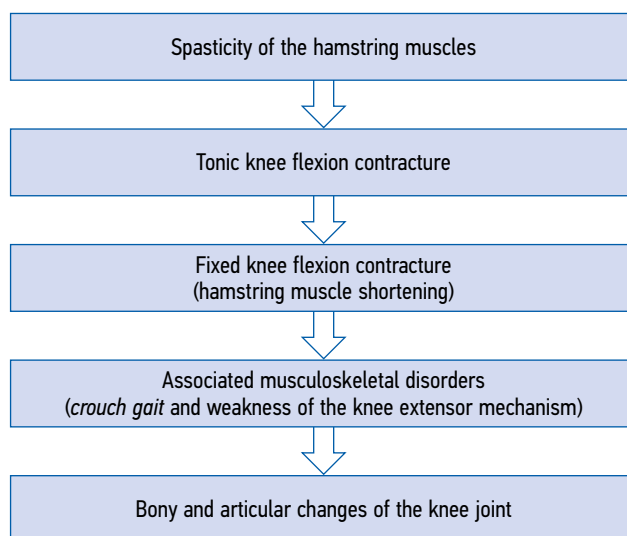
Knee flexion contracture (KFC) is the most common lower limb deformity among patients with CP, with a reported prevalence of 47%–53% [4, 5].

As children with KFC grow and gain weight, walking becomes increasingly energy-consuming. Thus, they tend to avoid prolonged standing, which may gradually lead to a decrease and eventual loss of motor skills and, consequently, to an increase in time spent in a seated position. Moreover, studies have shown that KFC may contribute to the development of contractures in adjacent joints and increase the risk of spinal deformities [6, 7].

Surgical treatment is indicated in patients with CP and KFC when the contracture is fixed and conservative treatment is ineffective. Considering the high prevalence of KFC and its significant negative impact on patients' quality of life, there is a need for a systematic scientific review of current surgical correction methods and the rationale for their use.

This study analyzed published scientific data on current surgical techniques for the correction of KFC in patients with CP, providing an assessment of their clinical effectiveness, the frequency of complications, and the factors for choosing the optimal treatment strategy.

Publications dedicated to the surgical treatment of KFC in patients with CP were investigated. Data search was conducted in the scientific databases PubMed, Google Scholar, Cochrane Library, Crossref, and eLibrary without language restrictions. The following keywords and phrases derived from them were searched: детский церебральный паралич/cerebral palsy, сгибательная контрактура коленного сустава/knee flexion contracture, удлинение сгибателей голени/hamstring lengthening, корригирующая надмыщелковая остеотомия бедренной кости/distal femoral extension osteotomy, походка приседая/crouch gait, надмыщелковая остеотомия бедренной кости/supracondylar femoral osteotomy, тугое колено/stiff knee, укорочение собственной связки надколенника/patellar tendon shortening, and передний гемиепифизеодез дистального отдела бедренной кости/anterior hemiepiphysiodesis of the dis-



**Fig. 1.** Mechanism of knee flexion contracture development in patients with cerebral palsy.

tal femur. Boolean operators “OR” for any of the keywords and “AND” for combination of all keywords were applied.

The inclusion criteria were randomized controlled trials, cohort studies and case series with 1–4 evidence levels, publications describing surgical treatment of patients with CP and KFC, and sources reviews. The exclusion criteria included clinical studies involving <10 patients, publications focused on conservative treatment of KFC in patients with CP, and commentary articles.

The initial search yielded 120 publications, including reviews and original research. After removal of duplicates and exclusion of non-eligible articles, 74 publications dated 1952–2024 were selected. These studies focused on soft-tissue methods for KFC correction, such as tendon transfers and hamstring lengthening, and bony methods for KFC correction, such as temporary hemiepiphysiodesis and distal femoral extension supracondylar osteotomy.

## Surgical Treatment Methods

KFC is a major orthopedic issue in patients with CP [8]. Several studies have shown that KFC severity correlates with motor abilities according to the Gross Motor Function Classification System (GMFCS), particularly in children at levels III–V [9].

Although the development of KFC, similar to other contractures in CP, is polyetiological, the predominant cause of their development is prolonged muscle spasticity. According to the theory proposed by Hof [10], persistent hypertonia during a child's growth causes a mismatch between the length of the tendons and muscles relative to the adjacent bony structures of the knee joint. Consequently, KFC manifests as shortening of the flexor muscles, such as the hamstrings (biceps femoris, semitendinosus, and semimembranosus

muscles) and gracilis muscle. With long-standing joint contracture, the heads of the gastrocnemius muscle, knee joint capsule, patella with its tendon, and femur and tibia alter gradually. Therefore, the surgical correction of this pathological condition is required to address the main pathophysiological components involved in the development of KFC.

Modern surgical treatments for KFC are divided into soft-tissue procedures, namely, tendon transfers and hamstring lengthening, and bony procedures, such as temporary hemiepiphyodesis and distal femoral extension supracondylar osteotomy.

### Tendon Transfer

In 1952, Eggers [11] was the first to propose correcting KFC through tendon transfer of the hamstring muscles (i.e., semitendinosus, semimembranosus, and biceps femoris) to the femoral condyles. The author hypothesized that hamstring transposition would improve movement coordination and decrease contracture by converting biarticular muscles into monoarticular ones [11, 12]. However, various complications were reported with this surgical technique, including genu recurvatum, restricted knee flexion, hamstring muscle weakening, increased lumbar lordosis, and KFC recurrence. Among the most significant complications were genu recurvatum and restricted knee flexion, which prompted other researchers to develop and propose their modifications of the hamstring transposition technique. Pollock [13] recommended transferring only the medial hamstring tendons, combining this with biceps femoris tenotomy in severe cases of flexion contracture. Evans and Julian [14] refined the original tendon transfer method. The modification involved partial transfer of the tendons (gracilis and semitendinosus muscles) and a change in their fixation points. Moreover, in his study, Reimers [15] concluded that distal or proximal hamstring lengthening does not lead to the previously reported complications and is therefore more effective.

KFC is often accompanied by internal rotation of the femur at the hip joint. Selber et al. [16] and Sung et al. [17] proposed simultaneously addressing both issues by transferring the distal tendons of the hamstring muscles. However, this technique was not widely adopted, as it proved ineffective in correcting internal femoral rotation and led to knee joint instability in some cases.

Currently, tendon transfer procedures are used infrequently owing to the complexity of the technique and high risk of postoperative complications. Consequently, Miller [8] and De Mattos et al. [18] preferred alternative methods, such as hamstring lengthening, which is considered more effective than tendon transposition and is associated with fewer complications.

### Hamstring Lengthening

Hamstring lengthening is considered the primary surgical procedure for treating patients with CP-related KFC, as it aligns with the pathophysiological principles underlying its development. The classic open technique involves Z-lengthening or complete transection of the distal tendinous portion of the biceps femoris, semitendinosus, semimembranosus, and gracilis muscles (Fig. 2). Additionally, a closed (percutaneous) technique may be used, which involves tenotomy of the aforementioned tendons through one or several skin punctures. Hamstring tenotomy is suitable for patients of any age. However, according to scientific data, children aged <5 years are at an increased risk of complications such as contracture recurrence or, conversely, hyperextension of the knee joint [19].

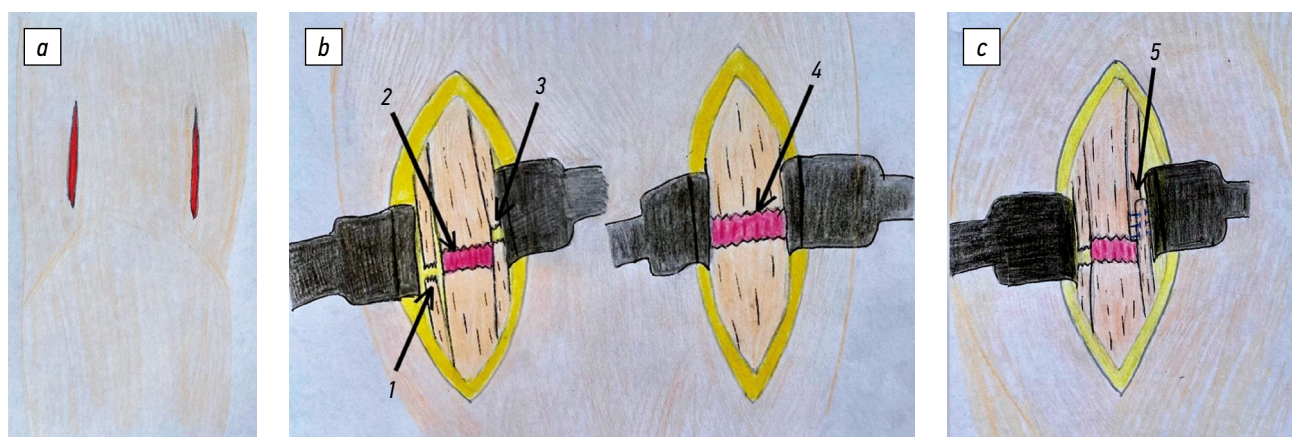
This method is applicable for KFC of any severity [8, 20, 21]. According to current guidelines, this procedure is indicated in a fixed knee flexion contracture of  $\geq 10^\circ$  and in a popliteal angle (PA)  $< 120^\circ$  [22].

Review of the scientific medical data revealed that surgeons using this correction method adhere to different treatment strategies: some prefer to lengthen only the medial hamstring tendons, whereas others address both the medial and lateral portions. According to several studies, open lengthening of the medial and lateral hamstring tendons demonstrates greater effectiveness and lower recurrence rate compared to isolated medial lengthening. Chang et al. [23] performed lengthening of the medial and lateral hamstring tendons and reported an increase in the PA from a mean of  $128 \pm 12^\circ$  to  $137 \pm 16^\circ$ , along with a decrease in KFC from  $8.9 \pm 4.6^\circ$  to  $4.6 \pm 5.7^\circ$ . Similarly, Dreher et al. [19] observed a  $28^\circ$  improvement in knee extension.

Despite these findings, most surgeons prefer medial hamstring lengthening alone, avoiding lateral intervention owing to a perceived higher risk of complications such as genu recurvatum, anterior pelvic tilt, and external torsional deformity of the lower leg bones [22, 24]. However, a definitive consensus on this issue remains unclear, given the limited number of high-level evidence studies comparing these two approaches.

Several studies have demonstrated favorable outcomes following medial hamstring lengthening alone, without intervention on the lateral group. Nazareth et al. [25] found that after open medial hamstring lengthening, knee flexion contracture during stance phase decreased by  $11.2^\circ$  during initial contact and by  $6.7^\circ$  during midstance. Similar results were reported by Haberfehlner et al. [26], who observed an increase in the PA by  $25^\circ$  from a preoperative range of  $100^\circ$ – $120^\circ$  and a decrease in KFC by  $19^\circ$  from a preoperative range of  $15^\circ$ – $45^\circ$ .

Several of the reviewed publications recommended the Z-lengthening technique for tendon elongation.



**Fig. 2.** Stages of the hamstring lengthening technique. *a*, Exposure of the medial and lateral hamstring tendons; *b*, Lengthening of the medial and lateral hamstring tendons: 1, gracilis tenotomy; 2, semimembranosus tenotomy; 3, semitendinosus tenotomy; and 4, biceps femoris tenotomy; *c*, Diagram of Z-lengthening of the medial group: 5, Z-lengthening of the semitendinosus muscle.

However, a number of studies described complete transection of the distal portion of the tendons responsible for knee flexion. In their research, Bekmez et al. [27], Damron et al. [28], and Bozinovski et al. [29] concluded that hamstring tenotomy yields outcomes comparable to Z-lengthening, decreasing the degree of KFC by  $14.4^\circ$  and increasing the PA by  $45^\circ$ . However, Damron et al. [28] reported the development of an extension contracture (stiff knee) after KFC correction in 13% of cases, which subsequently required surgical intervention. Other authors did not report deterioration in knee flexion postoperatively.

In recent decades, despite the proven efficacy of the open technique, percutaneous hamstring lengthening has been increasingly employed. According to the literature, this approach is comparable in effectiveness to the open technique. However, the closed technique for correcting KFC may be appropriate only in cases of mild contracture.

In a study, Mansour et al. [21] applied a percutaneous technique involving fractional lengthening of the medial hamstrings in the mid- and distal thigh and reported a  $12^\circ$  increase in PA from a preoperative range of  $110^\circ$ – $154^\circ$ . In a separate study, Khaje Mozafari et al. [30] also used a percutaneous lengthening method, achieving a  $34^\circ$  increase in PA from a preoperative range of  $110^\circ$ – $124^\circ$ . Their approach involved tenotomy of the medial hamstring group and, in some cases, the distal portion of the lateral group, potentially contributing to better KFC correction outcomes compared to those reported by Mansour et al. [21]. Similar results were obtained by Nazareth et al. [25] and Thompson et al. [31].

Moreover, several studies emphasized that the minimally invasive nature of the procedure allows for preserving muscle strength, which in turn shortens the duration of postoperative rehabilitation [25, 31, 32]. In a study by Hachache et al. [32], muscle strength in the lower limbs was measured using a handheld dynamometer before and 9 months after surgery, revealing only a 16.7% decrease

in the strength of muscles responsible for knee flexion. In contrast, in a study, Seniorou et al. [33] reported a 57.6% decrease in muscle strength after classic open hamstring lengthening.

Hamstring tenotomy is often combined with other surgical procedures on the lower extremities as part of a treatment based on the principles of single-event multilevel surgery (SEMLS) [31].

The concept of SEMLS was first described by William Little in 1862; since then, this approach has been used to treat this patient population globally [34–35] and in Russia [36]. SEMLS can be applied to both the upper and lower limbs and involves the simultaneous correction of all contractures and deformities of the operated limb in patients with CP. This approach aims to normalize biomechanical relationships within the joints and reduce immobilization time and allows for complete rehabilitation within a single recovery session, thereby improving treatment outcomes [37].

According to scientific data, in some cases of severe KFC, hamstring lengthening is combined with posterior capsulotomy of the knee joint. Beals [38] performed combined surgery on 11 knee joints (6 patients) and reported clinically significant improvement in 7 joints, whereas 4 knees demonstrated unsatisfactory outcomes in the upright position. The author attributed these poor results to weakness of the knee extensor mechanism. In a study by Woratanarat et al. [20], this method was applied in cases of contracture  $>20^\circ$ , with postoperative improvement observed as a decrease in KFC from  $26.5^\circ \pm 15.4^\circ$  to  $17.0^\circ \pm 15.5^\circ$  and an increase in the PA from  $110.4^\circ \pm 18.7^\circ$  to  $131.8^\circ \pm 19.9^\circ$ . Later, Umnov combined hamstring lengthening with posterior capsulotomy in cases of KFC exceeding  $30^\circ$  and, in certain cases, performed gastrocnemius head resection, achieving complete correction of contracture in 131 patients [12]. Despite the positive clinical effect of combining the abovementioned surgi-

cal techniques, this intervention is associated with a high risk of complications that can offset the achieved positive outcomes. These potential complications include injury to the neurovascular bundle, posterior subluxation of the tibia, posterolateral instability of the knee joint, and increased risk of contracture recurrence due to the intervention on the joint capsule [8, 12, 20, 39].

Notably, complete intraoperative correction of KFC by single-event hamstring tenotomy is not always feasible. In cases of KFC  $>10^\circ$ , single-event correction carries a high risk of traction neuropathy [12, 40]. To address this, Umnov recommended performing staged correction with plaster casts in the postoperative period to eliminate residual KFC, which allows for complete contracture correction and reduces the risk of traction neuropathy [12]. Similar approaches have been reported by other authors. Long et al. [40] and Westberry et al. [41] performed staged correction with plaster casting to eliminate residual KFC after surgical treatment, continuing until mild hypercorrection was achieved.

Staged corrections in plaster casts decrease the risk of traction neuropathies in the postoperative period; however, they are also associated with several complications, including severe pain syndrome, skin damage in the area of the patella and/or calcaneal tuberosity, and scar changes in the knee joint capsule [42].

Although hamstring lengthening is a common procedure, scientific data also show a considerable number of associated complications. The most frequent among them is injury to the common peroneal nerve and its branches [12, 24, 40, 42].

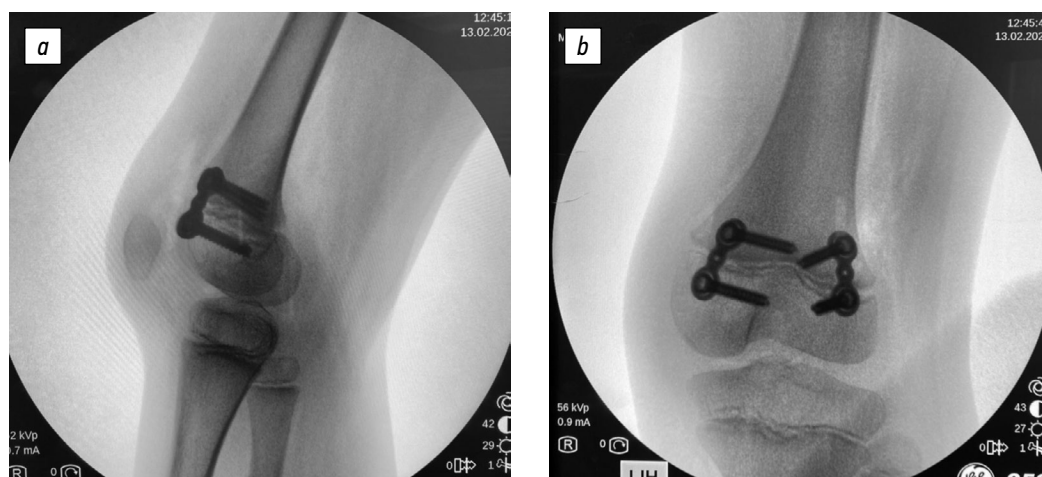
Kay et al. [24] described genu recurvatum as a complication resulting from excessive lengthening of the muscles responsible for knee flexion. Some studies also noted that hamstring lengthening may lead to muscle weakening [8, 24, 43]. However, Haberfehlner et al. [26] argued that the procedure does not affect muscle strength.

A relatively common complication of KFC correction is stiff knee, which is characterized by limited knee flexion when walking [8, 44, 45]. This may be related to increased tone in the knee extensor mechanism, altered muscle-tendon balance, and insufficient postoperative rehabilitation. Although many researchers consider this a complication, Popkov et al. [37] reported that in patients with CP, walking with extended knees increases their functional capacity and is more favorable than walking with knee flexion.

According to scientific data, the recurrence rate of KFC after hamstring lengthening is approximately 17%. Repeat correction using the same method is technically challenging because of the scar tissue formation. In addition, prolonged KFC leads to changes in the hamstring muscles and in the knee joint capsule, distal femur, and proximal tibia. Therefore, alternative surgical interventions should be considered and implemented.

### Guided Growth Technique

Temporary hemiepiphysiodesis, also called the guided growth technique, involves placing metal implants in the anterior metaphyseal-epiphyseal region of the distal femur. This approach allows for temporary deceleration of growth in this zone, thereby enabling flexion deformity correction. In 2001, the method was first described by Kramer and Stevens [46]. The authors used staples in patients with neuro-orthopedic condition and observed a decrease in KFC from  $0^\circ$  to  $11^\circ$  within 1.5 years after surgery. However, loosening of the staples was noted in some cases. In 2008, Klatt and Stevens [47] modified the technique by introducing the use of plates with screws, which eliminated the previously reported complication (Fig. 3). The efficacy of the technique has been confirmed by several subsequent studies. Al-Aubaidi et al. [39] reported an average KFC correction rate of  $0.3^\circ$  per month using plates, with a mean correction duration



**Fig. 3.** Radiographs of the knee joint after temporary anterior distal femoral hemiepiphysiodesis: *a*, lateral view; *b*, anteroposterior view.

of 20 months. At the time of plate removal, the residual contracture averaged  $10^\circ$  (ranging from  $0^\circ$  to  $30^\circ$ ), whereas the initial preoperative deformity was  $10^\circ$ – $40^\circ$ . In a study by Stiel et al. [48], the average correction rate of KFC was  $0.2^\circ$  per month. The mean correction period was 38 months, with a residual contracture of  $11^\circ$  (from a preoperative range of  $10^\circ$ – $50^\circ$ ). However, in some children with CP, the use of plate-and-screw constructs was associated with intermittent anterior knee pain. To minimize this complication, Kay et al. [49] proposed a percutaneous technique using cannulated screws. This approach decreased the incidence of persistent pain syndrome, minimized the invasiveness of the procedure, and facilitated earlier verticalization of patients. Scientific data do not report recurrences of KFC following temporary hemiepiphysiodesis; however, studies by Al-Aubaidi et al. [39] and Stiel et al. [48] noted KFC recurrence in patients with significant remaining growth potential.

Temporary anterior distal femoral hemiepiphysiodesis is the preferred surgical method for correcting KFC in patients with open growth plates and CP. However, it should be considered that this surgical technique targets the osseous component of the deformity, whereas in patients with CP, KFC is primarily caused by hamstring muscle shortening, particularly in younger children. Therefore, given the pathogenesis mechanism, in this group of patients, it is more appropriate to correct the contracture through soft tissue surgery. In contrast, this method is ineffective in older patients (with closed growth plates), in whom bony changes in the knee joint have already begun.

In addition, the guided growth technique requires a long period to achieve correction (ranging from 6 to 42 months, depending on the degree of contracture and the child's growth rate), and during this time, in the presence of existing KFC, patients with CP may develop contractures in adjacent joints, foot deformities, and sagittal spinal profile disorders, which may require complex multilevel surgical correction. Thus, clinicians tend to prefer other surgical methods that are faster and more effective [50].

### Distal Femoral Supracondylar Osteotomy

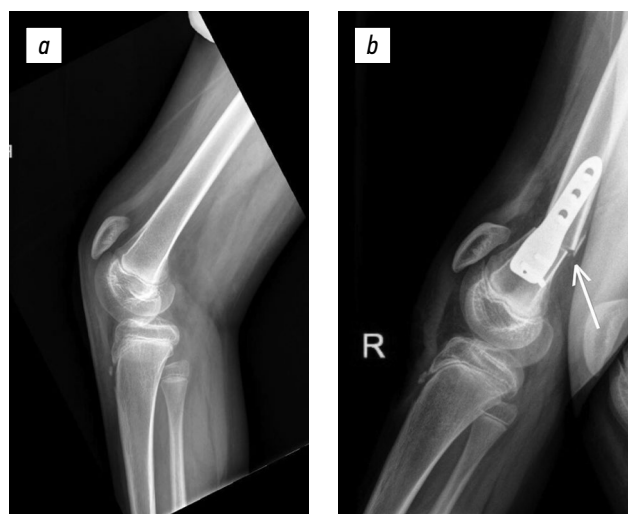
Distal femoral supracondylar extension osteotomy (DFSO) is a main surgical method for correcting KFC in patients with CP. Although the indications are similar to those for hamstring lengthening, DFSO is often considered an alternative treatment, especially in cases wherein the soft tissue component of the contracture is not predominant [51]. According to the 2022 Delphi consensus, the main indications for DFSO include knee flexion contracture of  $10^\circ$ – $45^\circ$  in older patients (aged  $\geq 10$  years); contracture recurrence after hamstring lengthening;

avulsion fractures of the patella; and the combination of KFC and femoral torsional deformity, which frequently coexists with and exacerbates knee flexion in older children [52]. DFSO is classified into extension osteotomy, shortening osteotomy, and extension-shortening osteotomy, although the indications for these approaches are identical. Studies have confirmed that mixed techniques are often used in clinical practice to correct KFC.

Extension femoral osteotomy aims to eliminate the preexisting flexion deformity of the distal femur, which should theoretically contribute to contracture correction. However, scientific data do not discuss this deformity as a possible surgical indication nor its presence at all. This raises several unresolved clinical questions: Does flexion deformity of the distal femur actually occur in KFC? Is its severity associated with the degree of KFC? Is it reasonable to perform DFSO in the absence of significant femoral flexion deformity? Further studies are required to answer these questions and to develop more precise criteria for the indications for this corrective technique.

Simultaneous correction of flexion and torsional deformities of the femur can be achieved using DFSO, which aligns with the principles of SEMLS.

DFSO presents various technical challenges. For KFC up to  $30^\circ$ , wedge-shaped extension osteotomy of the femur is recommended. In particular, Morais Filho et al. [53] modified the wedge osteotomy technique by preserving the posterior cortical bone, which increases the stability of the osteotomy site. In cases of severe contracture ( $>30^\circ$ ), trapezoidal femoral shortening is preferred, as it is beneficial for minimizing the risk of traction injury to the neurovascular bundle during single-event correction of KFC (Fig. 4). The degree of femoral shortening corresponds to the severity of the contracture [52–55].



**Fig. 4.** Lateral knee radiographs: *a*, preoperative radiograph showing a  $30^\circ$  knee flexion contracture; *b*, postoperative radiograph following distal femoral supracondylar extension-shortening osteotomy. The arrow indicates the angular deformity of the distal femur.

Shortening of the distal femur is an effective surgical technique that helps prevent traction-related complications; however, unlike wedge osteotomy, it does not limit knee flexion, which is crucial for preserving the range of motion. Bleck et al. [51] recommended performing DFSO in cases of recurrent contracture when hamstring lengthening and posterior capsulotomy of the knee joint proved ineffective. Later, a similar approach was described by Morais Filho et al. [53], and Miller [8] emphasized the effectiveness of DFSO for KFC  $>15^\circ$  in older patients.

The effectiveness of DFSO has been confirmed in several studies employing various modifications of the technique. Morais Filho et al. [53] performed extension DFSO in 21 patients and extension-shortening DFSO in 1 patient, reporting a decrease in KFC from  $16^\circ$  to  $5^\circ$ . Salami et al. [56] applied extension DFSO in 15 patients and observed an average reduction in contracture of  $8.5^\circ$ , which is comparable to the results reported by Morais Filho.

More pronounced outcomes were determined in studies using shortening DFSO. Park et al. [45] performed shortening DFSO in 28 patients and combined it with extension of the distal femoral fragment in 5 patients, which resulted in a decrease of contracture by  $26^\circ \pm 6^\circ$  and an increase in the PA by  $22^\circ \pm 5^\circ$ , improving gait biomechanics. Klotz et al. [57] reported a decrease in KFC from  $19^\circ$  to  $-2^\circ$  and an increase in the PA from  $118^\circ$  to  $137^\circ$  following extension-shortening DFSO.

Moreover, in a study, Geisbüsch et al. [58] performed extension-shortening DFSO with a mean follow-up period of 38 months (range: 24–55 months), reporting a decrease in KFC by  $12^\circ$  and an increase in the PA by  $34^\circ$ , which was less pronounced but clinically significant. Erdal et al. [59] confirmed the effectiveness of the method by obtaining comparable results.

Nabian et al. [55] performed shortening and extension DFSO in 15 patients within a single group without stratifying them by technique and confirmed the high effectiveness of the technique.

A comprehensive review of scientific data was conducted; no studies that performed a differentiated comparative analysis of the outcomes of extension and shortening femoral osteotomies were found. Existing data demonstrate high clinical effectiveness of both techniques for KFC correction; however, shortening osteotomy may provide more favorable functional outcomes owing to better joint congruence preservation and decreased risk of traction neuropathy. This assumption requires further investigation.

Despite its high effectiveness, DFSO is associated with the risk of complications. The recurrence rate of KFC varies from 3% to 27% [53, 54, 60, 61]. The main cause of recurrence in patients with open growth plates is incomplete skeletal growth. Additionally, Ezzat and Iobst [62]

and Liou et al. [63] reported postoperative valgus or varus deformity of the femur in this age group. The authors explained the possible causes of these complications as the retention of the posterior bony prominence during femoral wedge osteotomy, improper alignment of bone fragments, and osteosynthesis using angled plates. As a preventive measure, surgeons recommend a wedge resection of the bone fragment and using modern angular-stable plates, which can significantly reduce the incidence of complications [54, 61, 64].

Following DFSO, as with any osteotomy procedure, patients with CP may experience difficulties in achieving stable fixation of bone fragments due to reduced bone mineral density, particularly in individuals with higher GMFCS levels (III–V). Limited mobility, forced prolonged sitting posture, and repeated surgical interventions with extended immobilization during growth contribute to the development of osteopenia, increasing the risk of delayed bone consolidation, nonunion, and hardware migration with subsequent loss of surgical correction [54, 60, 65]. Several studies have demonstrated a direct correlation between the severity of motor impairment according to the GMFCS scale and decreased bone density, which in turn increases the possibility of low-energy fractures [66, 67]. Traditional methods of osteosynthesis, such as wire-based fixation with external immobilization and standard AO-type internal fixation devices, were not originally designed for use in conditions of decreased bone density and spastic deformity of the distal femur. Consequently, the use of long-leg casting becomes necessary, which restricts the scope of rehabilitation and adversely affects patients' quality of life.

In this context, a promising direction is the development of specialized fixation devices tailored to the anatomical and biomechanical characteristics of patients with neuro-orthopedic disorders. Such a device provides enhanced fixation stability in decreased bone mineral density, minimizes the risk of implant migration and nonunion, and accounts for flexion deformities and the anatomical features of the supracondylar region in this patient population. Optimizing implant design based on anatomical and radiographic data (e.g., MSCT of the femur) improves its congruency with the bone, reduces implant-related discomfort, and decreases pressure on the surrounding soft tissues, thereby reducing the need for prolonged external immobilization, accelerating rehabilitation, and improving functional treatment outcomes. This is crucial for enhancing the quality of life of patients with CP.

One of the most common complications is traction injury to the neurovascular bundle on the posterior thigh. However, currently, this risk has been almost entirely mitigated through femoral shortening, although the execution of this technique may be hampered

by limited access to specialized equipment and implants and insufficient surgical expertise [54, 64, 68].

**Distal Femoral Supracondylar Osteotomy and Extensor Mechanism Correction of the Knee Joint**

In the presence of KFC, weakness of the knee extensor mechanism develops, particularly involving the quadriceps femoris muscle. In such cases, surgical contracture correction may restore only passive knee extension, whereas persistent knee flexion remains during weight-bearing, ambulation, and upright posture [69, 70]. This results in overstretching of the quadriceps muscle and superior displacement of the patella—*patella alta* [8]. Thus, a vicious cycle develops, further exacerbating KFC, weakening the extensor mechanism, and increasing ankle dorsiflexion, a phenomenon called lever arm dysfunction. Notably, crouch gait can arise from excessive Achilles tendon lengthening (leading to loss of active plantarflexion and excessive dorsiflexion of the foot) and from the natural progression of crouch, as previously described. According to the literature, 21% of patients in this category exhibit persistent anterior knee pain, which may be associated with excessive load on the patellofemoral joint. In addition, prolonged tension on the patellar tendon may lead to avulsion of the distal pole of the patella and chondropathy of the tibial tuberosity [8, 71]. These complications significantly impair quality of life, limit the child’s mobility, and lead to loss of independent ambulation [72].

Based on this analysis, a combined approach was recommended for the treatment of longstanding KFC in patients with CP. This includes DFSO and correction of the knee extensor mechanism. The most commonly used methods for such correction are patellar tendon advancement (for patients with open growth plates) and tibial tubercle distalization (for patients with closed growth plates).

In a retrospective study, Stout et al. [54] analyzed the treatment outcomes of 73 patients and found that the use

of combined surgical methods led to better long-term results compared to isolated DFSO.

In a subsequent study, Boyer et al. [73] reported improvements in gait and a decrease in KFC in 51 patients treated using a combined approach. However, the outcomes were comparable to those achieved with the isolated technique.

In a study by Aroojis et al. [74] involving 26 patients, a decrease in KFC from 21° to 1° was observed. All patients markedly demonstrated improved function of the quadriceps femoris muscle.

In a study by Nabian et al. [55], significant correction of KFC and improvement in knee extension during all phases of gait were determined with the use of combined surgical techniques. These results support the rationale for a comprehensive treatment approach in patients with CP.

Modern surgical techniques, such as hamstring lengthening, temporary anterior distal femoral hemiepiphysiodesis, and DFSO, have demonstrated high clinical efficacy in restoring the range of motion in the knee joint. However, the indications for these interventions and their postoperative outcomes often overlap, which complicates the choice of the optimal technique in a specific clinical case. Both hamstring lengthening and DFSO may be indicated for similar degrees of KFC; however, their effects on biomechanics and long-term outcomes remain insufficiently studied. Therefore, comparative studies are warranted to clarify the indications for each surgical method (Table 1).

**CONCLUSION**

Scientific data review confirmed that KFC is a major orthopedic issue in patients with CP, significantly limiting their motor function and quality of life. The choice of treatment should be based on individual anatomic and clinical features, contracture severity, patient age, and GMFCS level. Surgical treatment should aim to eliminate KFC and correct lower

**Table 1.** Summary of modern surgical methods for the treatment of knee flexion contracture in patients with cerebral palsy

| Treatment method                                 | Patient age             | Indications<br>(degree of contracture)                                               | Recurrence rate                        | Complications                                                                                                  |
|--------------------------------------------------|-------------------------|--------------------------------------------------------------------------------------|----------------------------------------|----------------------------------------------------------------------------------------------------------------|
| Hamstring lengthening                            | Any age group           | No restrictions                                                                      | 17%                                    | Traction neuropathy, genu recurvatum, and <i>stiff knee gait</i>                                               |
| Temporary hemiepiphysiodesis                     | With open growth plates | 5°–30°<br>Recurrence after distal femoral osteotomy                                  | In patients with high growth potential | Pain, hardware migration, premature physeal closure, and recurrence in patients with high growth potential     |
| Distal femoral supracondylar extension osteotomy | From 10 years           | 10°–45°<br>Recurrence after hamstring lengthening or femoral supracondylar osteotomy | 3%–27%                                 | Valgus/varus femoral deformity, instability at the osteotomy site, hardware migration, and traction neuropathy |

limb joint biomechanics, which is particularly important in CP patients whose spasticity and muscle imbalance hinder normal gait restoration. One of the key factors that may influence the selection of the treatment method is the sagittal balance of the trunk and its changes following KFC correction. Special attention should be paid to the long-term effects of correction methods on sagittal alignment and its role in preventing secondary spinal deformities. Further studies are warranted to evaluate the impact of different approaches on spinopelvic relationships. The application of SEMLS combined with refined indications for correction techniques can improve treatment outcomes by enabling comprehensive deformity correction and optimization of biomechanical parameters. Another promising direction is the development of specialized metal fixation devices tailored to the anatomical and biomechanical characteristics of this patient population. These implants, optimized based on radiological data (e.g., multi-slice CT), may provide enhanced fixation stability under decreased bone density, minimize complication risks, and shorten rehabilitation periods—factors particularly important for improving functional outcomes.

Despite the considerable number of publications on this topic, several issues remain unresolved. The lack of randomized controlled trials, limited long-term outcome data, and insufficient comparative analyses hinder the development of a standardized treatment algorithm. Addressing these gaps requires further research, including long-term follow-up, comparative studies of different KFC correction techniques, clarification of their indications with consideration of sagittal balance, and clinical evaluation

of new fixation devices. A multidisciplinary approach involving orthopedists, engineers, and rehabilitation specialists may be beneficial in developing solutions that reduce the risk of recurrence and complications, improve functional capacity, and lower the disability level in patients with CP.

## ADDITIONAL INFORMATION

**Author contributions:** A.R. Mustafaeva: conceptualization; investigation, writing—original draft; V.A. Novikov: conceptualization, writing—review & editing; V.V. Umnov: writing—review & editing; S.V. Vissarionov: writing—review & editing. All authors approved the version of the manuscript to be published and agree to be accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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