Review article
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Orthopaedic complications of hemiparetic forms of cerebral palsy: problems of the lower extremities (literature review)

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Abstract

Introduction Spastic hemiplegia (a unilateral neurological disorder) is encountered more often in full-term infants. In most cases, the cause of the condition is intrauterine or perinatal stroke. Children with hemiparetic forms maintain cognitive and functional capabilities in combination with the ability to move independently. Among other forms of cerebral palsy, hemiparetic spastic forms range from 10.4 to 15.3 %. Types with mild motor impairments predominate according to the Gross Motor Function Classification System: 87.8 % are level I GMFCS, 7.1 % are level II GMFCS.

The purpose of the work was to summarize information on the use of orthopaedic interventions for hemiparetic forms of cerebral palsy, both from the point of view of their planning and completeness of correction of anatomical disorders including lower limb length discrepancy, and assessment of functional results based on gait analysis.

Materials and methods The search for publications was carried out in open electronic sources of medical literature PubMed, eLIBRARY, Scopus, Elsevier, Springer, Research Gate with a search depth of 20 years (2002–2022). The following inclusion criteria were used: systematic reviews of the literature, review articles, cohort studies on the topic of multilevel interventions for hemiparetic types of cerebral palsy.

Results and discussion Lower limb length discrepancy of 1 cm or more affects the kinematics of the affected and intact contralateral limb. The unaffected limb is characterized by a compensatory flexion in the hip and knee joints and excessive dorsal flexion in the stance phase. On the affected side, the contribution of shortening to the development of pathological kinematics of the pelvis and spine is especially important. There is a high probability of equinus contracture after surgical correction due to unresolved discrepancy in the length of the lower extremities. Methods for correcting length discrepancy are conservative (compensation with shoes), and surgical lengthening of the lower leg, epiphyseodesis of the contralateral limb, shortening of the contralateral limb. There is no opinion in the literature about the preference of this or that method, and on the necessary magnitude of limb length correction.

Conclusion The assessment of limb length discrepancy and contribution of this orthopaedic component to systemic movement disorders in spastic hemiparesis is based on computed tomography or magnetic resonance imaging, as well as on computer gait analysis. In the literature, the issue of limb length correction is considered separately from the complex of other orthopaedic interventions, while the features of correction with regard to spontaneous growth potential or after growth completion have not been defined. The advantage of equalizing the limb length in children with temporary epiphyseodesis over distraction osteogenesis is only supposed. There is not enough data on the effect of the limb length correction magnitude in patients with spastic hemiplegia on the parameters of computer gait analysis.

Keywords: unilateral cerebral palsy, orthopedic surgery, lower limb length discrepancy

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INTRODUCTION

Cerebral palsy (cerebral palsy) is a primary neuromotor disorder of the central nervous system that occurs in the prenatal or perinatal period and causes disturbances in muscle tone, movements and posture [1, 2]. Although the neurological disorder is not progressive, secondary complications that arise, mainly orthopaedic, lead to serious loss of functional abilities [3–5]. The incidence of cerebral palsy varies from 1.5 to 4.2 per 1,000 newborns, depending on the geographic region and the financial status of the population [6, 7].

Spastic hemiplegia (a unilateral neurological lesion), which orthopaedic complications are the subject of this review, occurs more frequently in full-term infants, and in most cases the cause of the disorder is an intrauterine or perinatal stroke [8]. Regularly, children with hemiparetic CP have preserved cognitive and functional capabilities in combination with the ability to move independently [9, 10]. Among other forms of cerebral palsy, hemiparetic spastic forms range from 10.4 to 15.3 % [7, 11]. Types with mild motor impairments predominate according to the Gross Motor Function Classification System [12]: 87.8 % are level I GMFCS, 7.1 % are level II GMFCS [11].

Hemiparetic forms of cerebral palsy are rarely accompanied by significant intellectual disorders, but the resulting orthopaedic disorders seriously affect the motor abilities and quality of life of children and adults [13–18]. The main orthopaedic secondary disorders in spastic hemiplegia are contractures of the ankle, knee and hip joints, equinovarus or equinovalgus foot deformities, torsion deformities of the femur, and limb length discrepancy [13, 15, 19–21].

The modern concept of surgical treatment of orthopaedic complications in children with cerebral palsy is multilevel surgical interventions on all components of the biomechanical limb chain, including cases of hemiparetic forms of cerebral palsy [15, 22–25].

Analyzing treatment planning and assessing the results of interventions, the researchers focus on the problem of limb length discrepancy in patients with spastic hemiparesis [26], on the anatomical and functional changes in the contralateral, neurologically intact limb [19, 27–29], as well as on a detailed computer analysis of the gait parameters in these patients [20, 30–33].

Purpose To collect and summarize the information on the use of orthopaedic interventions for hemiparetic forms of cerebral palsy, both in terms of their planning and completeness of anatomical correction, including lower limb length discrepancy, and the assessment of functional results based on gait analysis.

MATERIALS AND METHODS

The search for available publications was carried out in open electronic sources of medical literature PubMed, eLIBRARY, Scopus, Elsevier, Springer, Research Gate with a search depth of 20 years (from 2002 throughout 2022). The following inclusion criteria were used: systematic literature reviews, review articles, cohort studies on the topic of multilevel interventions for hemiparetic forms of cerebral palsy. The selection was carried out using key phrases in Russian and English: multilevel orthopaedic interventions (single-event multilevel surgery; lower limb length discrepancy; growth arrest, guided growth, epiphysiodesis; bone lengthening; gait analysis; unilateral cerebral palsy).

Exclusion criteria were case reports or case series, abstracts, duplication publications. The search revealed a total of 1,261 articles in the field of hemiparesis (unilateral cerebral palsy), 173 articles about multilevel interventions (single-event multilevel surgery), published between 2002 and 2022. Of these, 16 publications on multilevel orthopaedic interventions for hemiparetic forms of cerebral palsy were selected and analyzed, and 5 articles were selected on correction of limb length discrepancy in this disorder and 9 articles on the study of the functional results of multilevel operations for hemiparetic forms using gait analysis. We also selected 4 articles on the effect of orthopaedic pathology on a healthy limb in spastic hemiparesis.

RESULTS

Elements of orthopaedic pathology, the use of gait analysis in diagnosis and surgical planning

Table 1 presents orthopaedic problems in the lower limbs in patients with cerebral palsy which were the reason for seeking medical assistance, the object of diagnostic studies, as well as parameters of gait analysis.

Obviously, torsion deformities of the femur, ankle contractures, and foot deformities are the primary areas of concern. A minority of publications indicates or mentions specifically the correction of leg length discrepancy within the framework of multilevel interventions [34]. Moreover, some of them deal only with the methods for instrumental diagnosis of length discrepancy [14, 26] or with the study of the quantitative effect of shortening on gait parameters and the contralateral limb [19, 35, 36].

Table 1

Described orthopaedic CP complications, use of gait analysis in patients with hemiparetic forms of cerebral palsy

Published source	Hip and knee contractures	Ankle contracture	Femur and/or tibia torsion	Planovalgus foot deformity	Varus-supinated (adducted) foot deformity	Limb length discreapancy	Gait analysis
Krzak et al., 2015 [21]	+	+	–	–	+ (4 types are classified)	–	Computer 3D-analysis
Sclavos et al., 2023 [50]	+	+	–	+	–	–	Computer 3D-analysis
Winters et al., 1987 [37]	+	+	–	–	–	–	Observational analysis
Rethlefsen et al., 2006 [17]	+	+	+	–	+	–	–
Kim et al., 2022 [4]	–	+	–	–	–	+	–
Corradin et al., 2018 [27]	–	+	–	–	–	+	Observational analysis (Edinburgh scale)
Lee et al., 2013 [15]	+	–	+	–	–	–	–
Mork et al., 2001 [14]	+	+	+	+	+	+	–
McCahill et al., 2022 [20]	–	–	+	+	–	–	Computer 3D-analysis
Schranz et al., 2017 [31]	+	+	+	+	+	–	Computer 3D-analysis
Saraph et al., 2006 [45]	–	+	+	–	–	+	–
Schmid et al., 2016 [48]	+	+	–	–	–	+	Computer 3D-analysis
Rodda et al., 2001 [38]	+	+	+	+	+	–	Computer 3D-analysis
O'Sullivan et al., 2013 [40]	+	+	+	–	+	–	Computer 3D-analysis
Wren et al., 2005 [58]	+	+	+	+	+	–	Computer 3D-analysis
Elnaggar et al., 2020 [34]	+	+	+	+	–	–	Computer 3D-analysis

Classification of gait disorders in hemiparetic types of cerebral palsy

The first proposed classification of gait disturbances in unilateral spastic lesions is that of Winters et al. [37], which distinguishes 4 groups based on the pathology of movements of the limb on the affected side in the sagittal plane. The classification reflects the progression of disorders from the distal level to the proximal level (from movement disorders in the ankle joint to the hip) as the severity of the disease increases. Group I is characterized by an equinus position of the foot in the non-support phase of the step cycle, the absence of the first roll of the foot at the beginning of the support phase of the step. The disorders are caused by weakness or underactivity of the tibialis anterior muscle in comparison with the gastrocnemius and soleus muscles. In group II disorders, the foot is in an equinus position during the non-support phase of the gait cycle and in a constant position of plantar flexion during the stance phase. Group II disorders are caused by contracture of the triceps surae. In group III, in addition to the above-mentioned disorders of groups I and II, there is limitation of leg flexion at the knee joint in the non-support phase of the gait cycle, excessive flexion of the hip joint and lumbar hyperlordosis. In group IV disorders, in addition to previous disorders, there is a significantly restricted range of motion in the hip and knee joints throughout the gait cycle.

Winter's classification was refined by Rodda et Graham in 2001 [38], who added group (type) IIb (equinus contracture combined with hyperextension or recurvatum in the knee joint), and torsion deformities (pathological rotational alignment of the femur) were added to group IV. The Rodda classification [38] also proposes principles of conservative and surgical orthopaedic treatment for the correction of gait deviation. These two classifications are generally accepted and are used in determining the patient’s motor status and in planning multilevel interventions [39]. However, we underline that these classifications do not consider lower limb length disparities in assessing the severity of orthopaedic and motor impairments.

The problem of lower limb length discrepancy

A number of studies indicate the importance of the impact of difference in the lengths of the lower extremities on the formation of orthopaedic pathology and gait disorders [40], among other factors, demonstrating a significant correlation between length discrepancy and impaired parameters.

Zonta et al. [41] found a correlation between the magnitude of limb shortening and the degree of dependence of a patient with spastic hemiplegia on outside assistance. The same study showed a relationship between the amount of shortening and the duration of the initial double support phase for the affected limb. Researchers attribute these changes to decreased biomechanical leverage combined with muscle weakness and impaired selective control of muscle contraction.

In a walking test on an uneven surface, patients with lower limb length discrepancy due to hemiplegia show a larger step width and a more medial location of the center of body mass in the single-support phase of the gait compared to healthy peers [42, 43].

Eek et al. [44] found a decrease in walking speed and step length in children with spastic hemiplegia if the shortening value was 1 cm or more when walking barefoot.

The contralateral unaffected limb is also in unfavorable conditions, potentially leading to orthopaedic pathology [27]. During the stance phase of the gait cycle, excessive flexion at the knee and hip joints as well as excessive dorsiflexion of the foot is observed on the unaffected side [44, 45].

Yoon et al. [46] found valgus deformity of the foot of the contralateral unaffected limb in 40 patients (52 %) with spastic hemiplegia in a sample of 76 patients. The authors pointed to a 1 cm difference in the length of the legs as a significant limit for the development of pathology in a healthy limb.

The pathological anterior tilt of the pelvis and the magnitude of its asymmetrical rotations in spastic diplegia depend on the magnitude of limb shortening, which was found in children (sample 91 patients, average age 10.8 years), which was not considered in the above mentioned classifications [47]. Differences of more than 1SD from the group of healthy peers were found in 61.5 % of cases for pathological rotation of the pelvis and in 60.4 % of cases for its pathological tilt.

Schmid et al. [48] indicate the dependence of kinematic disorders of the spine on leg length discrepancy in combination with contractures of the hip joint on the affected side. Moreover, compensation for shortening with orthotic products is not enough, and the need for complex intervention and subsequent physical therapy is assumed.

A difference in length of 1 cm or more predisposes to recurrence of equinus contracture (deformity) after primary triceps lengthening (aponeurotomy by Strayer and other techniques), as Sala et al., indicated [49]. In another work, Sclavos et al, [50] defined the average statistical probability of plantar flexion of the foot in the non-support phase of the gait cycle after operations to eliminate equinus contracture being 25 %, but this risk is significantly higher for patients with spastic hemiplegia, up to 42 %. The authors opine that the combination of length discrepancy with reduced dorsal flexor strength and low selective control of these muscles is the cause.

In terms of diagnosing problems in spastic hemiplegia, including limb length discrepancy, Mork et al., [14] note the difficulties of fully identifying all pathological components by general specialists, suggesting a leading role of the neuropediatrician.

In relation to orthopaedic problems, in addition to computer gait analysis [39], computed tomography and magnetic resonance imaging (MRI) play a significant role in identifying structural disorders [51]. Thus, shortening of the lower limb in hemiplegia is almost completely determined by the segment distal to the knee joint: mainly the tibia, but shortening of the talus and calcaneus also contributes, which was revealed by MRI findings [26].

Correction of limb length discrepancy within the framework of multilevel interventions has not been defined in the literature. Multilevel orthopaedic interventions for spastic hemiplegia are aimed at eliminating torsion deformities in order to restore the magnitude of biomechanical levers, correct joint contractures and foot deformities [52, 53].

To correct the discrepancy in the length of the lower limbs, we observed several different strategic approaches (Table 2).

Based on the data, temporary epiphysiodesis looks preferable. The possibility of its use in combination with other elements of surgery for flexion of the tibia in children with cerebral palsy has been shown [53]. Bone age is a classical orientation for planning epiphysiodeses. However, the methodology of its interpretation in children with unilateral forms of spastic paralysis is controversial. Erickson et al., [54] found no effect of the hemiparesis side on the interpretation of bone age from hand radiographs, but Lee et al, [55] indicate a lag in bone age values on the side of hemiparesis in comparison with the intact arm. It is in this situation that the technique of temporary epiphysiodesis seems preferable, since it is reversible [56, 57], and there are no risks of its early use with overcorrection [58]. It should be noted that the epiphysiodesis material used should be strictly a titanium alloy for children with cerebral palsy: the possibility of performing MRI remains possible [59].

Table 2

Strategy for correcting length discrepancy in spastic hemiparesis, impact on gait parameters

Published source	Number and average age of patients	Method of correction	Impact on the gait parameters	Comments
Corradin et al., 2018 [27]	10 patients, 12.7 years old	Epiphysiodesis. Initial mean length discrepancy 3.4 cm, final discrepancy 1.2 cm (mean follow-up period after surgery 6.7 years)	Improved kinematics of the healthy (disappearance of compensatory excessive flexion in the knee and hip joints and excessive dorsiflexion of the foot) and the affected limb	Edinburgh Visual Scale — Observational Gait Analysis
Eek et al., 2017 [44]	10 children, more than 1-cm shortening	Shoe compensation	Increased step length and walking speed, symmetry of the duration of the support phase of the gait cycle	Comparison with 10 healthy peers. Computer 3D gait analysis
Schmid et al., 2016 [48]	10 adolescents, shortening of more than 1 cm	Compensation with orthotic products	Compensation for shortening using conservative methods did not lead to an improvement in the kinematics of the pelvis and spine due to the presence of contractures of the hip joint	Comparison with 10 healthy peers. Computer 3D gait analysis
Saraph et al., 2006 [45]	11 children, 11.7 year old, discrepancy more than 2.5 cm	Tibial lengthening with external fixation	Improvement of kinematics of the healthy side (disappearance of compensatory excessive flexion in the knee and hip joints and excessive dorsiflexion of the foot)	Computer 3D gait analysis, study period — 3 years after lengthening
Jahmani et al., 2020 [60]	1 patient with hemiparesis among 6, mean shortening in the group 4.2 cm	Simultaneous shortening on an intramedullary rod	Only the anatomical result achieved was stated	X-ray telemetry only, no gait analysis

DISCUSSION

The relevant literature that was reviewed considers limb length correction as a separate problem in the complex of other surgical interventions. However, features of this correction in regard to potential spontaneous growth or after its completion have not been defined. The advantage of equalizing the length of the limbs in children with the method of temporary epiphysiodesis over distraction osteogenesis is only assumed and is performed as a separate procedure. There is insufficient data on the influence of the limb length equalization magnitude in patients with spastic hemiplegia on the parameters of computer gait analysis.

In the literature, there is also no established opinion regarding the magnitude of correction. Given the low selective control and weakness of the dorsal flexors of the foot, Corradin et al. [27] recommend leaving a residual discrepancy of 0.5–1.5 cm. On the other hand, length discrepancy of 1 cm or more negatively affects the kinematics of the pelvis and spine during walking [47, 48] and thus has indications for compensation [44, 48].

Such a wide uncertainty in the issue of correction of orthopaedic components of hemiparetic forms of cerebral palsy justifies a comprehensive study that would compare the results with known publications.

The assessment of length discrepancy and the contribution of this orthopaedic component to systemic motion disorders in spastic hemiparesis are based on computed tomography or magnetic resonance imaging, as well as computer gait analysis. The same methods should be used for assessing long-term treatment results.

CONCLUSION

Currently, the researchers are turning their focus to the problem of limb length discrepancy in patients with spastic hemiparesis, to the anatomical and functional changes in the contralateral, neurologically intact limb.

A fairly wide range of methods for correcting limb length discrepancy, both conservative and surgical, are found in the literature. But the total of such studies is extremely limited in number, and patient samples are small. It can be concluded that, despite the consensus on the need to correct shortening as an important component of the kinematic disorder, there is no consistent consensus on the method of choice. Moreover, the available works present surgical correction of length discrepancy as a separate stage, and not as a part of multilevel interventions.

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