REVIEW

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Hallux valgus in Equino-Planovalgus Foot Deformity in Children With Cerebral Palsy and Its Etiopathogenesis: A Review (Part 1)

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ABSTRACT

BACKGROUND: *Hallux valgus* in children with cerebral palsy is an understudied problem. Treatment approaches are generally applied as a secondary measure, often after the child starts complaining at an older age following correction of contractures and other foot deformities. Moreover, there are no established methods for the early prevention or treatment of *hallux valgus*. Understanding the fundamental mechanisms of etiopathogenesis and biomechanical disturbances during gait is crucial for developing preventive and therapeutic strategies for this patient population.

AIM: To analyze international studies of foot deformities in children with cerebral palsy and compare these findings with biomechanical studies in patients with idiopathic *hallux valgus* without neurological pathology.

METHODS: Sixty-four scientific articles and publications retrieved from multiple databases without time restrictions were reviewed.

RESULTS: Equinoplanovalgus foot deformity is a major etiopathogenetic factor in the development of *hallux valgus* in children with cerebral palsy. Biomechanical alterations associated with *hallux valgus* are characterized by limited dorsiflexion of the hallux, excessive dorsiflexion of the first ray, restricted supination of the hindfoot and midfoot, and increased plantar flexion of the ankle joint during the terminal stance phase. In equinoplanovalgus deformity, excessive pronation of the hindfoot and midfoot cannot be compensated because of the limited range of motion of the midtarsal joint, causing restricted midfoot supination and the inability to activate the locking mechanisms of the midfoot and forefoot during terminal stance.

CONCLUSION: Any biomechanical disturbance within the complex multisegmental structure of the lower extremity that reduces hindfoot and midfoot supination, causes first ray eversion, and limits hallux dorsiflexion may contribute to deformity. The diversity of motor disorders, contracture patterns, and deformities in children with cerebral palsy indicates the need for further research aimed at identifying the specific factors involved in *hallux valgus* formation. Such findings may be beneficial for developing preventive and therapeutic strategies for early-stage deformities.

Keywords: *hallux valgus*; equinoplanovalgus foot deformity; cerebral palsy; first ray of the foot; first metatarsophalangeal joint; gait analysis.

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НАУЧНЫЙ ОБЗОР

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Hallux valgus при эквино-плано-вальгусной деформации стоп у детей с церебральным параличом. Этиопатогенез. Обзор литературы. Часть 1

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АННОТАЦИЯ

Обоснование. В настоящее время *Hallux valgus* у детей с церебральным параличом — достаточно малоизученная проблема. Подходы к лечению осуществляют по остаточному принципу при появлении жалоб ребенка в старшем возрасте после коррекции контрактур и деформаций стопы. Кроме того, отсутствуют методы профилактики и лечения на ранних стадиях формировании деформации до появления жалоб больного. Понимание фундаментальных процессов этиопатогенеза, а также биомеханических нарушений при ходьбе у пациентов данной группы особенно важно при разработке методов профилактики и лечения.

Цель — анализ данных мировой литературы, касающейся теорий формирования деформации у детей с церебральным параличом в сравнении с результатами биомеханических исследований при *Hallux valgus* у пациентов с идиопатической формой заболевания без неврологической патологии.

Материалы и методы. В работе использован материал 64 научных статей и публикаций различных баз данных без ограничения периода поиска.

Результаты. Эквино-плано-вальгусная деформация стоп рассмотрена как ведущий фактор этиопатогенеза *Hallux valgus* у детей с церебральным параличом. Биомеханические изменения при *Hallux valgus* характеризуют ограничение разгибания I пальца, избыточное разгибание первого луча стопы, ограничение супинации заднего и среднего отделов, увеличение подошвенной флексии стопы в голеностопном суставе в конечные фазы периода опоры. При эквино-плано-вальгусной деформации стопы избыточная пронация заднего и среднего отделов стопы не может быть компенсирована по причине малого сектора движения в среднетарзальном суставе, что приводит к ограничению супинации среднего отдела стопы и невозможности активировать механизмы блокировки среднего и переднего отделов стопы в конечные фазы периода опоры.

Заключение. Любые биомеханические нарушения сложной многозвеньевой системы нижней конечности, приводящие к уменьшению супинации заднего и среднего отделов стопы, эверсии первого луча и, как следствие, ограничению разгибания I пальца стопы могут способствовать формированию деформации. Разнообразие двигательных нарушений, сочетаний контрактур и деформаций у пациентов с детским церебральным параличом требует дальнейшего исследования с целью выявления факторов, приводящих к формированию *Hallux valgus*. Результаты данных исследований могут помочь в разработке методов профилактики и лечения на ранних этапах развития деформации.

Ключевые слова: *Hallux valgus*; эквино-плано-вальгусная деформация стоп; детский церебральный паралич; первый луч стопы; первый плюснефаланговый сустав; анализ походки.

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ЭКО • ВЕКТОР

BACKGROUND

Several factors influence the development of the hallux valgus of the great toe (hereafter referred to as *hallux valgus*). In adults with idiopathic *hallux valgus* and in children with the juvenile form of the disease without any neurological pathology, the primary etiopathogenetic factors include: wearing inappropriate footwear [1]; forefoot overload associated with sports, ballet, or prolonged walking [2]; obesity-related excessive body weight [3]; hereditary predisposition [4]; age [4]; sex [5]; metatarsus primus varus [6]; flatfoot [7–10]; morphological characteristics of the first metatarsal head [11]; variations in foot types [12]; muscle imbalance [13]; atypical insertions of foot muscles [14, 15]; hypermobility of the first ray in the context of generalized joint hypermobility [10, 16]; and evolutionary remnants inherited from great apes, such as oblique orientation of the first cuneometatarsal joint and pronation of the first metatarsal [17–19]. Congenital *hallux valgus* is associated with polydactyly, duplication of the articular surface of the first metatarsal, and the presence of an *os intermetatarseum* [20].

Posttraumatic hallux valgus develops following the rupture of the medial collateral ligament of the first metatarsophalangeal joint [21], Lisfranc joint injuries, fractures of the first metatarsal [22], and fractures of the tibial bones with associated damage to the medial plantar nerve, leading to impaired innervation of the flexor hallucis brevis, adductor hallucis, and first lumbrical muscle [23]. In rheumatoid arthritis patients, hallux valgus is linked to inflammatory alterations in the joint capsule and articular cartilage, resulting in muscle imbalance and subsequent joint instability [24, 25].

Hallux valgus in children with cerebral palsy (CP) is a serious clinical concern regardless of the child's gross motor function level. Indications for surgical correction include the patient's complaints of pain, difficulty wearing footwear, and cosmetic concerns [26]. However, the current understanding of this pathology in children with CP remains limited, often classifying hallux valgus as an associated or tertiary manifestation of foot deformity. Consequently, treatment is typically administered on a secondary basis, with surgical correction performed at an older age after addressing all lower limb deformities and joint contractures [26].

Moreover, the underlying mechanisms of *hallux valgus* in this patient group remain unclear. There is also a paucity of data concerning its course, prevalence, age of onset, and predisposing factors. This gap in knowledge contributes to the absence of preventive and early-stage treatment strategies for *hallux valgus* prior to the manifestation of clinical symptoms.

The diversity of biomechanical impairments and compensatory motor mechanisms in children with CP complicates the identification of key pathomechanical elements. Nonetheless, the previously documented range of factors contributing to deformity development in neurologically healthy individuals suggests the existence of a common underlying mechanism for the development of *hallux valgus*.

Most studies describing various lower extremity biomechanical parameters in *hallux valgus* have been conducted among adults with the idiopathic form of the disorder and without neurological pathology.

The **study aimed** to review internationally published data on the theories underlying the development of deformity in children with CP and to compare these findings with results of biomechanical studies involving patients with idiopathic *hallux valgus* without neurological pathology.

METHODS

PubMed, eLibrary, Google Scholar, and the Cochrane Library were searched for data without regard to publication dates. A total of 64 scientific articles and publications were reviewed. The descriptive characteristics of the gait phases and the kinematic terminology for the gait cycles commonly employed in both Russian and international practice were applied [27, 28].

RESULTS

Etiopathogenesis of the *Hallux Valgus* in Children With Cerebral Palsy

Most authors [26, 29, 30] consider equino-plano-valgus foot deformity (EPVFD) to be the primary etiology of *hallux valgus* in children with CP. EPVFD causes the anteromedial region of the foot to be overloaded during walking. This foot position results in lateral displacement of the hallux at the metatarsophalangeal joint, either under or over the second toe. A significant torque generated at the first metatarsophalangeal joint during the terminal stance phase induces the medial displacement of the first metatarsal and an increase in the intermetatarsal angle. Valgus deviation of the hallux further triggers subluxation at the first metatarsophalangeal joint and consequently to sesamoid bone subluxation. The equinus component of the deformity increases axial loading on the distal phalanx of the hallux, overloading the lateral growth plate zones of the proximal and distal phalanges and the first metatarsal bone, and promoting progressive deformity as the child grows (Fig. 1).

Based on clinical observations, Holstein et al. [29] concluded that *hallux valgus* in patients with CP develops in the context of a typical spastic gait, characterized by a flexion-adduction posture at the hip joints, flexion

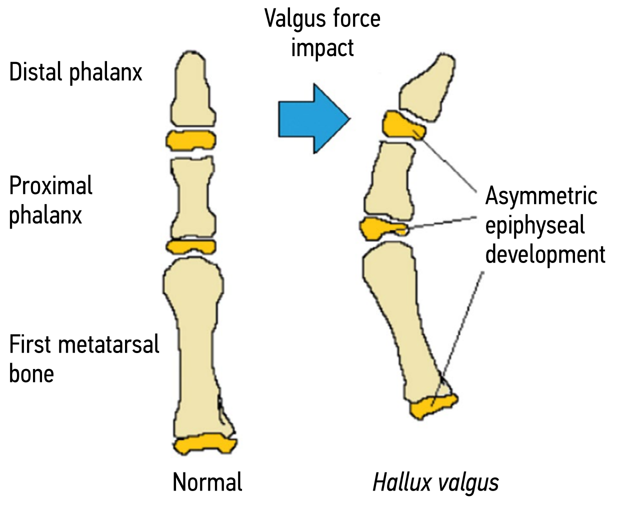

Fig. 1. The effect of valgus forces in EPVFD, causing asymmetric loading of the growth plates of the distal and proximal phalanges of the hallux and the first metatarsal bone.

contractures at the knees, and equinus positioning of the feet combined with external tibial torsion. According to the researchers, this gait pattern initially contributes to EPVFD, which subsequently leads to forefoot deformity. Furthermore, the authors described a case in which a patient with equinovarus foot deformity developed *hallux valgus* and planovalgus foot deformities following posterior tibial tendon lengthening.

Jenter et al. [30] and Renshaw et al. [31] identified hyperactivity of the peroneal muscles, along with specific anatomical features, as one of the primary etiologies of *hallux valgus* in patients with CP. Specifically, the tendon of the peroneus longus muscle, due to its fibrous extension, attaches to the oblique head of the adductor hallucis, which inserts at the base of the proximal phalanx of the hallux. According to the authors, spasticity of the peroneus longus muscle in the presence of such anatomical characteristics causes lateral displacement and valgus positioning of the hallux. The attachment of the adductor hallucis to the lateral sesamoid bone contributes to the lateral displacement of the flexor hallucis brevis tendon, further worsening the alignment of the hallux at the first metatarsophalangeal joint. As the valgus deformity progresses, abductor hallucis becomes ineffective, and a contracture develops due to tightening of the lateral capsule of the first metatarsophalangeal joint. Finally, displacement of the tendons of the extensor hallucis longus and flexor hallucis longus worsens the lateral deviation of the hallux, positioning it beneath or above the second toe. The valgus positioning of the hallux during walking amplifies the external valgus forces impacting it, contributing to further deformity progression.

S.K. de Velde et al. [32] investigated the link between motor activity levels, the type of neurological impairment, and the clinical and radiographic presentation of hallux deformities in patients with CP. The authors discovered that symptomatic *hallux valgus* is more prevalent in CP patients with GMFCS Level II and III motor function, whereas non-ambulatory patients with Levels IV and V motor function, or those with dystonia and mixed muscle tone, more frequently develop *hallux flexus*. This phenomenon can be explained by the presence of functional global flexor synergy reflexes in the lower extremities of patients with GMFCS Levels IV and V motor function, leading to flexion of the hips and knees and dorsiflexion of the foot due to hyperactivity of the tibialis anterior muscle. The pull of the tibialis anterior increases the dorsiflexion of the first metatarsal, promoting hallux flexion and the development of *the hallux flexus*. However, the authors noted that some patients with *hallux flexus* also exhibited an element of valgus deviation of the hallux. The development of *hallux valgus* in GMFCS Level I CP patients without pronounced hindfoot valgus is a manifestation of idiopathic adolescent *hallux valgus*.

Biomechanical Studies of the Hallux Valgus Deformity

Pedobarographic studies have shown rather inconsistent results. For example, Bryant et al. [33] observed increased pressure in the anteromedial forefoot region during walking in adults with idiopathic hallux valgus and planovalgus foot deformity compared to healthy individuals. Comparable outcomes were reported by Plank [40]. Conversely, similar studies by Komeda et al. [34] and Mueller et al. [35] revealed decreased pressure under the first metatarsal head. Blomgren et al. [39] found that in patients with *hallux valgus*, the maximal plantar pressure was localized to the area of the fifth toe. Galica et al. [38] noted reduced pressure in the lateral forefoot of idiopathic *hallux valgus patients*, suggesting an associated planovalgus deformity. Dietze et al. [37] observed a shift in the center of pressure projection toward the central forefoot during the terminal stance phase in patients with idiopathic *hallux valgus*. In contrast, Martínez–Nova et al. [36] reported no significant differences in the dynamic pedobarographic findings between patients with *hallux valgus* and healthy individuals (Fig. 2).

When analyzing the spatiotemporal gait parameters, Menz et al. [41], Mickle et al. [42], Taranto et al. [43], and Glasoe et al. [44] found no significant differences between hallux valgus patients and healthy individuals. However, these authors noted a lack of prospective studies addressing this issue. In contrast, Klugarova et al. [45] found that in comparison to individuals without this condition, *hallux valgus* adversely impacts the spatiotemporal gait parameters as well as the kinematic characteristics of the lower limbs and pelvis.

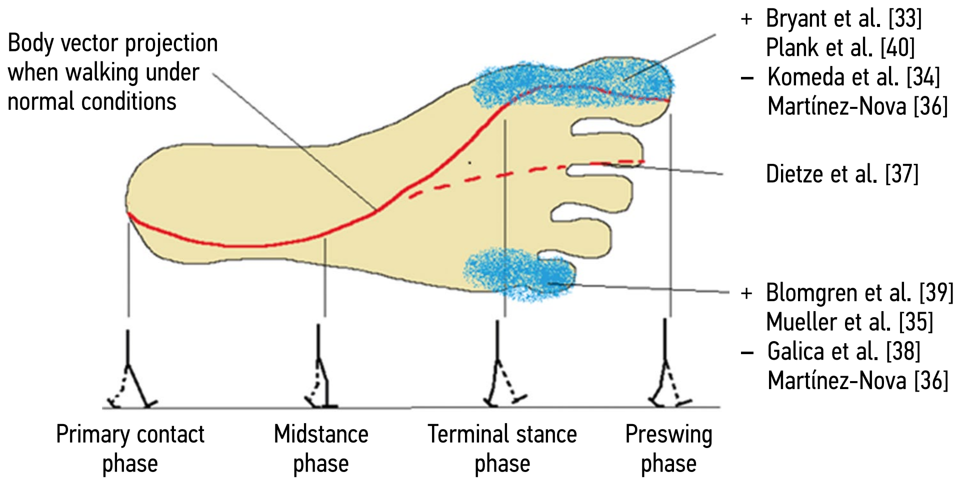

Fig. 2. Results of pedobarographic studies demonstrating the pressure distribution and ground reaction force projection in patients with hallux valgus. "+," study results indicating increased load in the designated area; "–," study results indicating decreased load in the designated area.

There is a lack of significant evidence in scientific literature supporting abnormal muscle activity in this pathology. Only Shimazaki et al. [47] reported early activation and increased intrinsic foot muscle activity, specifically the abductor hallucis, flexor hallucis brevis, and extensor hallucis brevis, during initial heel contact in *hallux valgus* patients, attributing this to the need to stabilize the hypermobile first ray.

Kinematic studies revealed significant deviations from the typical joint angles of the lower limb and foot during various phases of the gait cycle in hallux valgus patients (Table 1). For example, Deschamps et al. [51] reported that patients with idiopathic hallux valgus and a control group of healthy people exhibited significantly different joint motion volumes. In the *hallux valgus* group, excessive dorsiflexion at the first metatarsophalangeal joint and excessive dorsiflexion of the first ray relative to the hindfoot were observed during the swing phase. During the terminal stance, reduced hindfoot supination and ankle dorsiflexion were noted. Similar findings were reported by Glasoe et al. [44]. Compared to healthy controls, reduced stance phase ankle dorsiflexion in *hallux valgus* patients was also described by Hwang et al. [50].

Kozakova et al. [48] documented that idiopathic *hallux valgus* patients, compared to the healthy control group, experienced increased plantar flexion of the ankle during the initial stance phases and decreased dorsiflexion during midstance, along with greater knee extension during the late swing phase. They noted reduced hip abduction as well as decreased pelvic tilt and rotation in the frontal plane.

Similar findings regarding increased plantar flexion of the ankle during the early stance phase in patients with juvenile *hallux valgus* were reported by Janura et al. [49].

Dietze et al. [37] studied first ray instability in *hallux valgus* patients without neurological disorders. They concluded that in the presence of the deformity, the first ray exhibits significantly greater dorsiflexion during the terminal stance phase.

Shereff et al. studied the centers of rotation of the first metatarsophalangeal joint in patients with *hallux valgus* and *hallux flexus* compared to healthy individuals during walking. In *hallux valgus* patients, the compressive phase of motion at the first metatarsophalangeal joint was activated earlier than normal and prolonged in duration. The researchers attributed this to the restricted motion of the first ray, which resulted in limited dorsiflexion of the hallux.

Table 1. Alterations in kinematic parameter of lower limb joints in patients with idiopathic hallux valgus compared to healthy individuals.

Swing phase	Initial stance phase	Midstance phase	Terminal stance phase
Increased dorsiflexion of the first ray [37]	Increased plantar flexion of the ankle [51]	Decreased ankle dorsiflexion [44, 48–50]	Increased dorsiflexion of the first ray [51]
		Increased knee extension [48]	Decreased ankle dorsiflexion [44, 51]
		Decreased hip abduction [48]	Decreased hindfoot supination [44, 51]
		Decreased pelvic tilt and rotation [48]	

DISCUSSION

Although most researchers directly link *hallux valgus* to EPVFD, the authors of this article believe that this perspective does not adequately elucidate the pathogenesis because not all patients with CP and even severe EPVFD develop *hallux valgus*. Moreover, according to Church et al. [53], foot shape in CP patients can improve with growth, whereas hallux valgus angles tend to deteriorate with age, as shown by Min et al. [54].

One etiopathogenetic element in the development of hallux valgus in CP patients is the overactivity of the peroneus longus tendon, which extends toward the adductor hallucis. However, investigating this mechanism would require intramuscular electromyography to be combined with gait kinematic and kinetic analysis in CP patients, which is extremely challenging to implement in practice.

Notably, excessive dorsiflexion of the first ray, restricted supination or increased eversion of the foot, increased knee extension during the late swing phase, reduced walking speed, and decreased pelvic motion amplitudes are all important lower limb biomechanical changes linked to hallux valgus.

Typically, achieving effective push-off and forward propulsion requires adequate dorsiflexion of the first metatarsophalangeal joint. This movement is possible only with adequate plantar flexion or eversion of the first ray. Although the mechanism of first ray plantar flexion remains unclear, stabilization of the midfoot and forefoot structures provides resistance against ground reaction forces localized anterior to the metatarsophalangeal joint, generating a strong dorsiflexion torque at the first ray and medial column joints. These midfoot and forefoot locking mechanisms are activated sequentially and are linked to the hindfoot and midfoot supination [55] (Fig. 3).

It can be hypothesized that the development of *hallux valgus* in the presence of planovalgus foot deformity arises as a compensatory mechanism in the context of restricted dorsiflexion of the hallux, which is primarily caused by initial limitations in flexion and eversion of the first ray due to inadequate hindfoot and midfoot supination and the failure to sequentially activate the foot locking mechanisms. In this scenario, as the center of gravity progresses toward the forefoot, restricted dorsiflexion at the first metatarsophalangeal joint impedes the forward movement of the body's center of mass. This may trigger compensatory mechanisms primarily aimed at increasing or altering movement patterns in adjacent joints. The development of the *hallux valgus*, which facilitates forward body movement, may be one such mechanism. Due to the absence of adequate skeletal stabilization of the midfoot and forefoot, there is overload at the articulations between the first metatarsal and medial cuneiform bones, as well as between the medial cuneiform and navicular bones. This causes excessive dorsiflexion, abduction, and supination of the first ray, which can clinically and radiographically manifest as varus positioning of the first metatarsal, hypermobility of the first ray, and forefoot supination (Fig. 4).

Many authors have reported an association between hallux valgus and planovalgus foot deformity [7–10]. However, some studies have failed to validate this relationship [9, 56, 57]. The variability of these findings may be attributed to the lack of a standardized, unified definition of the planovalgus foot deformity [58].

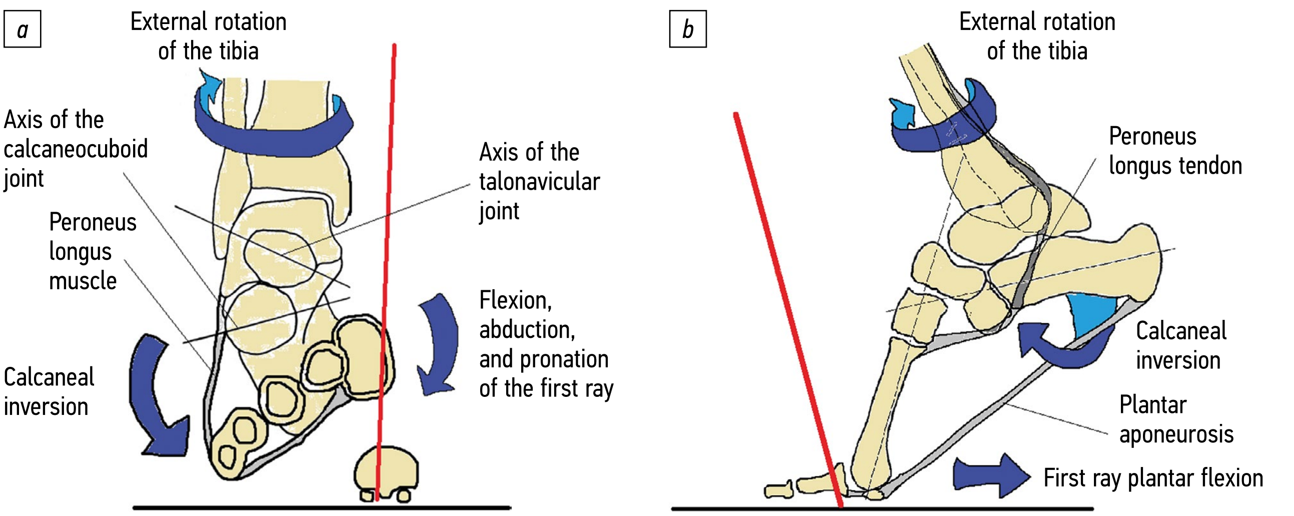

Fig. 3. Alignment of the midfoot and forefoot components during the terminal stance and preswing phases under normal conditions in the frontal (*a*) and sagittal (*b*) planes. The red line represents the ground reaction force vector. Supination of the calcaneus and abduction and dorsiflexion of the talus disrupt the alignment of the talonavicular and calcaneocuboid joint axes, thereby blocking motion around the axes of the midtarsal (Chopart) joint. The supinated position of the cuboid bone aggravates the flexion moment at the base of the first metatarsal relative to the base of the second metatarsal, counteracting the dorsiflexion moment caused by the ground reaction force.

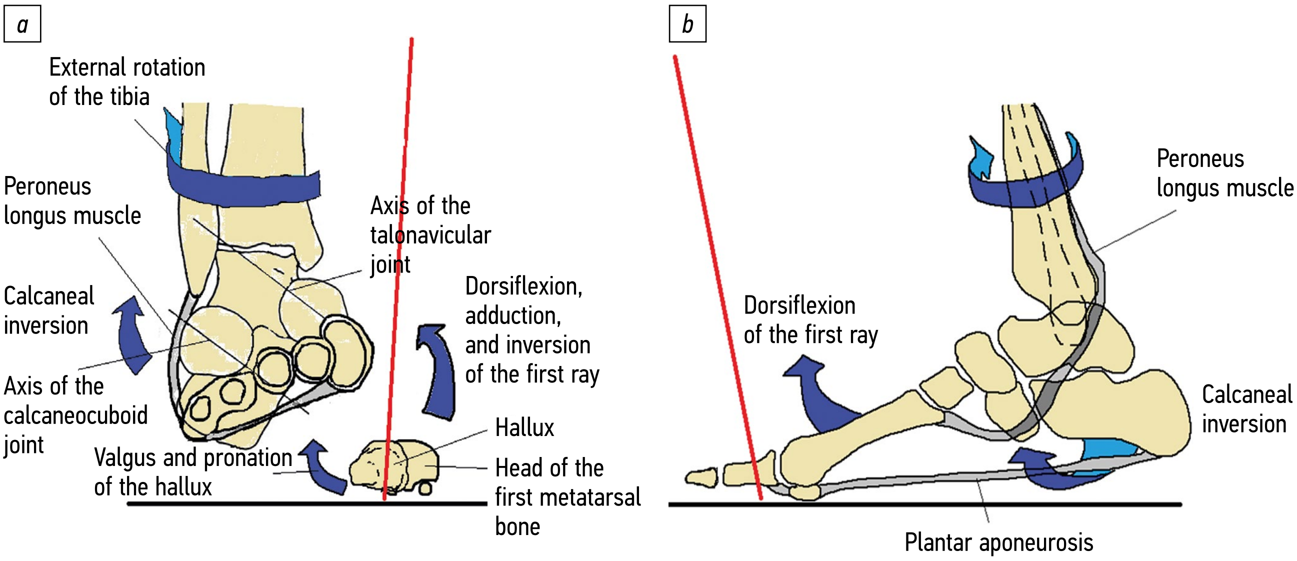

Fig. 4. Terminal stance and preswing phase position of the midfoot and forefoot components in the frontal (*a*) and sagittal (*b*) planes in the hallux valgus. The red line represents the ground reaction force vector. Inadequate supination of the hindfoot and midfoot impedes effective resistance to the dorsiflexion torque generated by the ground reaction force acting on the first ray, contributing to its inversion, dorsiflexion, adduction, and supination as well as instability of the medial cuneonavicular joint and the Chopart joint, thereby limiting dorsiflexion at the first metatarsophalangeal joint. Valgus deviation of the hallux may occur as a compensatory mechanism for restricted hallux dorsiflexion.

From a biomechanical perspective, planovalgus foot deformity may be a significant contributing factor in the development of *hallux valgus*. In planovalgus deformity, excessive pronation of the hindfoot and midfoot cannot be compensated due to the limited range of motion at the midtarsal joint, causing restricted midfoot supination and failure to activate the forefoot locking mechanisms [59, 60].

Notably, complicated interactions between the ankle, knee, and hip joints are necessary for the proper functioning of every foot segment. Although several studies have documented the sagittal plane kinematic features of these joints during gait in patients with idiopathic *hallux valgus*, the characterization of rotational movements has only been identified in the work by Shih et al. [61], who discovered elevated internal hip rotation during the terminal stance phases in patients with hallux valgus compared to healthy individuals.

The authors of this article contend that movements in the horizontal plane at the leg joints play a crucial role during the terminal stance phases. These phases, which occur in tandem with foot supination, are distinguished by external rotation of the tibia, femur, and pelvis in normal gait [62]. It can be assumed that internal rotation contractures and internal torsional deformities of the lower limb bones, which are prevalent in CP patients, may limit foot supination during the stance phase and impede the activation of the midfoot and forefoot locking mechanisms [63, 64].

It can thus be concluded that any pathology altering the functioning of the complex multisegmental system of the leg by restricting midfoot supination and first ray dorsiflexion during the terminal stance phases may contribute to the development of *hallux valgus*.

CONCLUSION

Equino-plano-valgus foot deformity may be an important predisposing factor for the development of *hallux valgus* in CP patients. Any biomechanical impairment within the complex multisegmental system of the lower extremity that limits midfoot supination, first ray dorsiflexion and eversion, and consequently hallux dorsiflexion, may lead to this deformity.

The diversity of motor impairments, contracture patterns, and deformities observed in CP patients highlights the need for additional research to identify the factors causing *hallux valgus*. The results of these studies may assist in developing strategies for preventing and treating the deformity in its early stages.

ADDITIONAL INFORMATION

Author contributions: *V.V. Umnov, D.S. Zharkov:* source analysis, writing – original draft; *V.V. Umnov:* conceptualization, writing – review & editing (staged editing); *V.A. Novikov:* source search and analysis, writing – review & editing; *D.S. Zharkov:* source analysis, writing – review & editing, writing – original draft; *D.V. Umnov:* source search and analysis. All authors approved the version of the manuscript to be published and agreed 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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