TECHNOLOGICAL SOLUTIONS FOR DESIGNING ORTHOPEDIC SHOES TAKING INTO ACCOUNT THE BIOMECHANICS OF MOVEMENT

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Annotation: *Orthopedic shoes designed specifically for people suffering from diseases of the lower extremities. A significant place in the production of orthopedic shoes occupy design for children with cerebral palsy disease. The paper provides an analysis of samples of footwear, joint kinematics during walking, movement phases, the biomechanics of the foot, on the basis of which the proposed classification of the basic designs of shoes for different seasons socks. Using the obtained classification criteria when designing shoes for patients with cerebral palsy will provide better its production with increasing rehabilitation effect.*

Keywords: *orthopedic footwear, polymer, foot, joint.*

The production of orthopedic footwear is a very complex and multifaceted process. Orthopedic footwear is specially designed footwear that provides support to people suffering from various lower limb conditions. Footwear for special medical purposes has been around for a long time and has always been focused on maintaining foot mobility. A significant part of orthopedic footwear production is designed for children with cerebral palsy (CP). These children typically walk with their legs bent, adducted, and rotated inward, often with weight on the forefoot, while people with normal feet rely more on the heel and outer arch.

We, researchers from the Department of Light Industry Engineering and Design at Bukhara State Technical University, are conducting a study with the prosthetic and orthopedic company Prado N on satisfaction with orthopedic footwear for this condition. The data obtained is used to adjust and improve shoe designs.

An analysis of industrial footwear samples revealed that, based on medical indications, two shoe models in various modifications are the most popular: high-heeled sandals with a 9 cm (3.5 in) upper and boots with stitched uppers with a height of 10 cm (4.1 in) (the upper height is specified for a track length of 135 mm or more). Both models are designed to provide ankle support. As part of ongoing research, it is necessary to determine the precise degree of foot fixation rigidity required for different types of cerebral palsy. To achieve this goal, it is necessary to characterize lower limb abnormalities in the main forms of cerebral palsy (Table 1).

Table 1

The influence of the form of cerebral palsy on deviations in the lower extremities

Form of cerebral palsy	Deviations in the lower limbs
Spastic diplegia	Tetraparesis, in which the arms are affected to a lesser

	extent than the legs. Righting reflexes develop by age 2, in most cases with significant limitations. Pathological synergies are observed, resulting in abnormal limb alignment, contractures, and deformities.
Double hemiplegia	Tetraparesis, in which the arms are affected as severely as the legs, or more severely. Muscle rigidity is characteristic. Righting reflexes are either completely or almost completely absent, and consequently, children cannot sit, stand, or walk.
Hyperkinetic form	Hyperkinesis of various types. Paralysis, paresis, delayed reduction of tonic reflexes (up to 2-3 years), delayed development of righting reflexes. Muscle rigidity.
Atonic-astatic form	Characterized by low muscle tone in the presence of pathological tonic reflexes. Absence or underdevelopment of righting reflexes is characteristic.
Hemiparetic form	Delayed reduction of tonic righting reflexes (up to 2-3 years), trophic disorders, slowing of bone growth, and consequently, shortening of the length of paretic limbs

Regarding the kinematics of movement, research shows the emergence of an initial flexion angle in all leg joints, superimposed on angular displacements, and a reduction in the amplitude of all angular displacements in the major joints of the lower extremities. Figure 1 shows a graph of angular displacements in the joints of the lower extremities during walking in normal subjects and in patients with cerebral palsy (dashed line) [1].

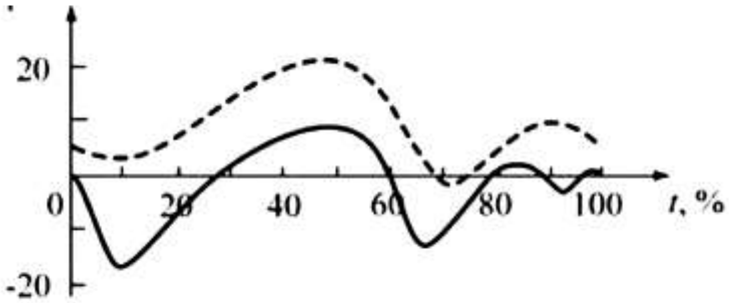


Fig. 1 – Graph of angular displacements in the joints of the lower limbs during walking in normal subjects (solid line) and patients with cerebral palsy (dashed line)

It is important to note that when patients with cerebral palsy walk, the normal ratio of the durations of the support and swing phases of the gait is disrupted. Specifically:

- the swing phase is shortened by 16%, the double support phase increases sharply (by 73%). All of this indicates a decrease in the patients' stability while walking;

- at the same time, a re-phasing within the support phase occurs – the time spent on the heel and entire foot decreases, and the time spent on the forefoot increases.

This redistribution of support areas necessitates the design process be carried out in zones corresponding to the different phases of gait. Accordingly, the emphasis should shift to either the upper or the vamp.

The stride length in patients with cerebral palsy decreases by an average of 25%, and the average walking speed decreases by 27%. The pattern of movements in the major joints of the lower extremities also changes significantly during walking. The following types of changes are typically observed:

- the initial flexion angle in all leg joints, taking into account the constant component on which angular movements are superimposed (on graphs, this is expressed as an upward shift of all kinematic curves from the zero line, corresponding to standing with straight legs);

- a reduction in the amplitude of all angular movements and their first two derivatives in the major joints of the lower extremities;

- a shift in the beginning and end points of individual movement phases (Fig. 1).

A comparison of joint kinematics during walking in normal subjects and those with cerebral palsy shows that patients with cerebral palsy exhibit a pronounced flexed leg position (forward tilt of the lower leg) and a brief heel roll. Dorsiflexion during the support phase increases due to the preliminary forward tilt of the lower leg, while secondary plantar flexion decreases, indicating insufficient push-off of the foot from the ground.

When the foot is transferred, the toe may touch the supporting surface, and therefore, the shoe design and the shape of the toe area should ensure a painless roll in the toe area.

It should be noted that cerebral palsy is associated with disturbances in muscle tone, which plays a leading role in the reconfiguration of movement. Analyzing the gait process of a healthy person [2], we distinguish the following phases:

1) heel support, during which the knee joint is maximally extended;
2) roll of the foot from the heel to the toe of the forward leg;
3) full support;
4) roll onto the toe, during which the plantar flexion of the foot and extension of the knee joint occur simultaneously;
5) push of the toe off the support;
6) hanging position of the foot.

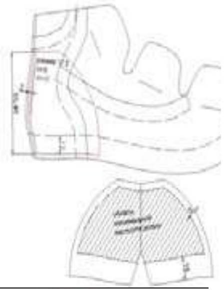
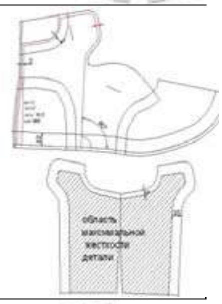
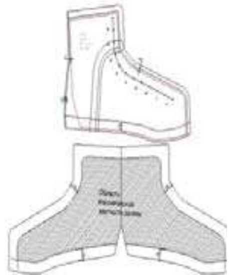
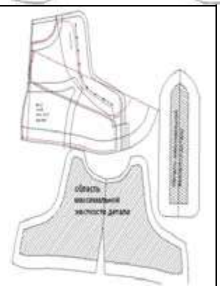
Considering the fact that cerebral palsy is characterized by muscle rigidity, paresis, underdevelopment of the righting reflexes, etc., it can be concluded that movement correction is necessary with the help of orthopedic devices.

As noted previously (Table 1), each form of cerebral palsy is characterized by varying deviations in the lower extremities. In all cases, additional ankle fixation with rigid components is necessary, but their configuration varies [2-3]. Four main degrees of foot fixation within the shoe space have been identified, related to the rigidity of the components (Table 2).

Since the angular displacement of the ankle joint decreases with movement, as shown in Table 2, it is advisable to use rigid polymer components in the ankle area in all models. These components typically increase the rigidity of the uppers and heels, providing enhanced ankle support.

Studies of foot movement phases and ankle joint condition have shown that foot support time and support area are related to the complexity of shoe design. For example, in cases of maximum forefoot support, shoe designs are designed with increased rigidity of the frame components in the toe-pappus region. For longer heel support phases, frame components in the heel-shaft region are reinforced. Four groups of designs have been proposed depending on the foot support area. Thus, the biomechanics of movement in children with this condition determines the choice of design and manufacturing solutions for footwear [3].

Table 2 Degrees of foot fixation in various shoe designs

Construction	Purpose	Construction
High-back designs	For minor deviations in the lower limbs	
High-rigid boot designs	The degree of foot fixation has been significantly increased	
Designs with high, rigid uppers and rigid sides	In case of significant deviations in the ankle joints (valgus, equinovarus of the foot, adduction of the forefoot)	
Shoe designs with maximum ankle support	Marked deviations in the lower limbs	

A study of the range of footwear used for cerebral palsy patients allowed us to categorize the main designs for different seasons. The following are considered basic:

1) sandals with a high upper and a full opening for the foot. This model is the most popular among orthopedic footwear, as it can be prescribed for various lower

limb conditions associated with cerebral palsy. This design is suitable for both ankle joint contact defects and foot paresis.

2) Shoes with a vamp with a raised tongue and a raised shaft. In addition to the rigid shaft, the design also includes a rigid tongue for increased ankle support. It's important to note that a closed shaft makes it difficult to fit shoes for patients with severe ankle contact and foot paresis. A vamp with a raised tongue provides enhanced ankle support.

3) Shoes with high tops and closed toes are also very popular among patients with cerebral palsy. It's worth noting that this model has a number of limitations when it comes to prescription and excludes significant deformities in the lower extremities. This shoe model is absolutely not suitable for patients with severe ankle contractures, foot paresis, toe deformities, etc.

Variable solutions for basic models are available for all shoe fit groups. The use of classification criteria in the design of footwear for patients with cerebral palsy has resulted in higher-quality production and improved rehabilitation benefits.

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