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Original Contribution

ORTHOPEDIC EQUIPMENT FOR THE HABILITATION OF CHILDREN FROM 2 TO 7 YEARS

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ABSTRACT
The aim of this study is to implement the method developed by Prof. E. Dukendjiev through the creation of robotic reciprocal complexes and test them on patients. The main idea is that these complexes should be intended for domestic use. A complex of technical assistive devices (TADs) for the treatment and rehabilitation of patients aged 2 to 7 years with muscle activity deficit and muscle control deficit. The reciprocal orthotic complexes for imperative locomotion incorporate original solutions aimed at enabling imperative movements and providing optimal individual structural and functional parameters of movement for each patient. The theoretically developed robots "Bionika - I" for swimming-crawling movements and quadrupedal locomotion, and the locomotor robot "Bionika - II" for bipedal walking, have been implemented. These robots allow for mass robotic habilitation and rehabilitation of children aged 2-7 years and provide a unique opportunity to transfer their treatment from the clinic to the patient's home, with parents replacing medical personnel. Habilitation both accelerates the processes significantly and increases the treatment effectiveness. The use of negative work mode with external energy is a fundamentally new basis for developing a habilitation plan, significantly reducing the required biological resources of patients.

Key words: imperative locomotion, cerebral palsy

INTRODUCTION

There are numerous options for orthopedic assistive devices and systems for the rehabilitation of adults after injuries and spinal cord disorders worldwide. However, there is a lack of pediatric options specifically designed for children aged 2 to 7 years without congenital movement patterns that require rehabilitation. The term "habilitation" shall be used to denote the process of developing correct habits and skills in the absence of initial abilities. To habilitate means to make someone capable, competent, and suitable, the initial development of some non-existent skills. Gait disorders are the main consequence of functional impairments and musculoskeletal disorders. Most of these disorders are multifactorial and have both neurological and non-neurological components. In children with congenital pathologies such as cerebral palsy, there are generally no neurological connections between the spinal and cerebral cortex and the muscular units (1).

METHODS

Walking is a highly automated and reflexive movement ingrained in human nature. This gives a chance that, with the help of specialized technical assistive devices, it is possible to restore or create this movement from scratch. In cerebral palsy, motor disorders manifest as pathological redistribution of muscle tone, decreased muscle strength, and impaired interaction between agonist and synergist muscles (2). Advancements in modern fundamental and clinical neurophysiology highlight several morpho-functional processes in the human neuromuscular system that can be targeted by therapeutic and rehabilitation interventions using systems of forced (imperative) locomotion (3):

1. Functional training and education of the spinal central pattern generator and motor commands.

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A crucial role in this training is played by the afferentation generated by forced movements from proprioceptors.

2. Enhancement of excitability and activity in movement control cortical structures. Several studies have demonstrated the effectiveness of treadmill training with patient weight compensation in this regard.

3. Increase in the intensity of neuroplastic processes in the brain. It has been shown that an effective endogenous signal, whose production is stimulated by purposeful and regular motor activity, is the brain-derived neurotrophic factor.

4. Improvement of regional (muscular and cerebral) blood supply and energy metabolism, which, in turn, promotes anabolic processes. The involvement of stem cells in the regeneration of spinal and brain structures and the possibility of awakening them during habilitation measures remains controversial.

RESULTS

In summary, the method involves two energy-related influences (on cell biochemistry and blood circulation) and two informational influences (afferentation and pre-cell genesis). To implement all stages of locomotion, two robots have been created: "Bionika - I" (Figure 1, Figure 2) (swimming, crawling, quadrupedal movement) and "Bionika - II" (bipedal walking) (Figure 3). The "Bionika - I" robot replicates the biomechanics of swimming movements, crawling, and quadrupedal movements. It employs single-parameter control and a single energy channel with cascade branching.

- Movement shall be carried out on a plane using spatial support, locomotion, and manipulation;
- Symmetrical gait shall be mirrored sequentially in two phases, involving reciprocal movements of the left arm-left leg and then the right arm-right leg;
- The abdomen of the torso maintains constant contact with the supporting surface, sequentially transitioning between the left-central-right sides;
- There are two functional phases: support and swing, with time intervals between them;
- Control operates on the principle of "the body follows the head," where the front limbs follow the head's turns alternately, and the rear limbs reciprocate.

The key aspect of solving the single-parameter task of energy supply and control is transforming the child's three-dimensional crawling and quadrupedal movement into contact with a two-dimensional support surface while considering the aforementioned requirements. To maintain the child's three-dimensional mobility, kinematic suspension of the limbs and head shall be introduced, without fixing angular movements in the joints. The locomotion robot "Bionika - I" **(Figure 1, Figure 2)** for crawling and quadrupedal movement consists of a rectangular tubular frame on supports. Suspended beneath it on belts is a platform for the torso, mounted under the frame, which rotates around the longitudinal axis of the platform with quasi-maximus crosspieces. Rollers are hung on the left and right beams of the crosspieces, which are lubricated by ropes. Orthopedic rings and straps for grasping and suspending the patient's limbs and head are attached to them. Mounted to the lower part of the platform, rotating around the longitudinal axis, is a cascade mechanism of quasi-maximus crosspieces with internal engagement and equal, periodic intervals of segmental rotation. Altogether, including the platform rotation around the longitudinal axis, they transform the planar movement of the crosspieces into spatially kinematically interconnected movements of the patient's limbs and head for crawling on the abdomen and quadrupedal movement (4 -5).

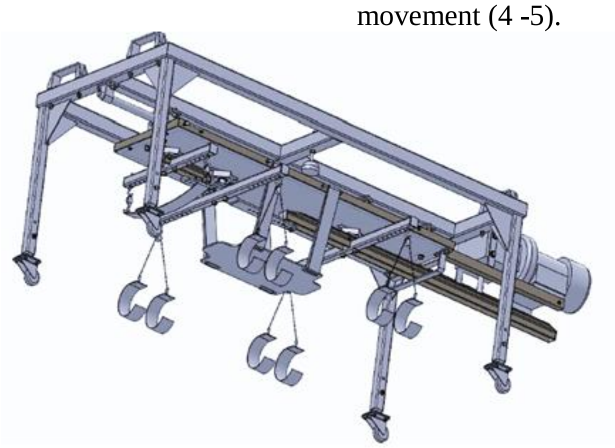

Figure 1. "Bionika - I" Locomotion Robot Construction

Figure 2. "Bionika - I"

For bipedal walking, the locomotor robot "Bionika - II" (**Figure 3**) (4-5) has been developed, operating in automatic mode with adjustable parameters and working independently of the patient's condition. It implements the method of compensating for the deficit of muscular and controlling activity using external energy.

The rehabilitation locomotor robot includes Module One - the reciprocating orthotic system by E. Dukendjiev for the entire body. It consists of hinged and kinematically interconnected modules for the upper and lower limbs, torso, and mechanical power drives. Module One is attached to Module Two, which is a patient verticalization device with an attached active horizontal reciprocating mechanism for delivering external energy to the patient. Module Three is a well-known system for supplying external energy to the patient and features a moving belt, a hand support stand (for patients using only the reciprocating system lower part), a control panel, and parameter measurement.

Figure 3. "Bionika - II")

During the walking process, one leg resting on the moving belt is pulled backwards due to friction forces between the orthotic sole and the belt, performing a backward swing. Simultaneously, the second leg, not in contact with the belt, is forcibly swung forward due to the cyclic movement. When the rocker amplitude is exhausted, and due to the pendulum motion, the first leg lifts up from the moving belt and initiates a swing forward, pushed by the frontal reciprocating force and attracted by the second leg's weight in the active horizontal reciprocating mechanism. When the amplitudes of both reciprocating mechanisms are exhausted, the second leg lifts up and detaches from the belt, while the first leg begins a backward support swing. This cyclic process continues until the external energy is turned off by pressing the STOP button on the control panel. The friction force between the supporting orthotic sole and the belt, combined with the attracting force of the active reciprocating mechanism, leads to forced and kinematically synchronized movements of the torso and upper limbs, facilitating automatic movements of the entire patient's body during walking, even in cases of significant deficit in muscular and controlling activity.

CONCLUSIONS

The use of locomotion and locomotor robots, such as "Bionika" for imperative locomotion shall offer several advantages:

- It reduces the motor habilitation and rehabilitation duration significantly when compared to traditional therapeutic exercises;
- Locomotor therapy accelerates the process of restoring or acquiring standing and walking skills;
- Through repetitive training and biological feedback, it helps form a walking stereotype and step rhythm;
- The locomotor robot elicits a powerful positive psychoemotional response in children, increasing motivation for independent walking.

In addition to changes in the functional state of muscles and limbs due to training, specific changes in the biomechanical and innervation structure of walking are observed. Key locomotor characteristics improve, such as increased walking speed, step length, and rhythmicity.

The use of bionic insoles and involving specific foot areas in the support reaction during the roll phase from the moment of the front push to the end of the back push; Not only do highly automatic motor functions improve, but speech and intellectual abilities also normalize, and sensory sensitivity significantly increases. Training on the imperative locomotion complex in the treatment program leads to improvements in both temporal and kinematic gait characteristics, enhancing mobility during walking (6).

The imperative locomotion complex facilitates the development of a physiologically correct walking pattern by reorganizing pathological locomotor patterns. This is achieved primarily by increasing the range of angular velocity for hip and knee flexion-extension, and also, which is extremely important, by reducing the range of angular velocity for abduction-adduction in the hip joints. By employing monotonous mechanical forced movement of all body parts, a process is initiated that does not require reorganization of the central nervous system but instead signifies a transition from forced conditional reflex activity to unconditional reflex activity. The basis for this transition is formed at the microstructure level of movement control - during the excitation phase of muscles (active or forced). Locomotor centers are released from inhibitory influences and become amenable to corrective interventions due to the connection of motoneurons of different muscles and groups in the spinal cord, where spinal interactions organizing rhythmic step-like movements occur. The forced stretching of muscles by the orthotic system, using external energy, leads to the conversion of mechanical energy into biomechanical energy based on the biomechanical potentiation of muscles. This results in an increased ability of muscles to perform positive work immediately after active muscle stretching. Moreover, forcibly stretched muscles can synthesize chemical compounds that serve as an additional source of mechanical work produced.

Due to the periodic compression of veins resulting from muscle contractions and the presence of venous valves, blood is forced to flow from the veins into the heart. Therefore, muscle contraction acts as an additional "pump" for blood circulation. Furthermore, muscular activity reduces capillary hydrostatic pressure, thereby reducing the tendency for fluid accumulation and edema formation in the feet during standing. Habilitation both speeds up the processes significantly and increases the treatment effectiveness. The use of the negative work mode with the aid of external energy represents a fundamentally new foundation for the development of a restorative plan while significantly reducing the biological resources required for patients. The Bionika-I robots (Figure 1, Figure 2), designed for swimming-crawling movements and quadrupedal locomotion, as well as the Bionika-II locomotor robot (Figure 3), for bipedal walking, have been successfully implemented. They enable mass robot-assisted habilitation and rehabilitation for children aged 2-7 years, and provide a unique opportunity to extend rehabilitation beyond the clinic to the patient's home (the robot requires an area of 1.5 m² and a power supply of 220 V), with parents replacing medical personnel.

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