A Novel Approach to the Rehabilitation of Disordered Motor And Speech Functions In Patients with Paralysis of Cerebral Origin

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In 1991, a group of clinicians and physiologists developed a novel method for rehabilitative treatment of patients with motor and speech disorders of cerebral origin. More than 200 of the patients treated with this method had been suffering from pediatric cerebral palsy in the residual stage and only two had been paralyzed as a consequence of brain trauma. The theoretical approach described below can only be called “novel” with certain reservations because some of its elements have been in clinical use over many years.

Briefly, the method involves the use of a special device which is built into the suit the patient wears and which normalizes to some extent the trajectory characteristics of the locomotor acts executed by the patient’s torso and lower limbs in the presence of an extra load of 15-40 kg imposed by the device in the direction of the long axis of the body. This brings toward normal the impaired proprioceptive impulse traffic from the system of joints, ligaments, and muscles to various structures of the motor-kinesthetic analyzer, including its cortical representation. The resultant diminution of the pathologically active proprioceptive impulse traffic and its progressive normalization also optimize the activity of the efferent (executive) component of the motor-kinesthetic analyzer, thereby breaking the “vicious circle” that exists in the condition under consideration. This process, whereby the pathologic mutual influences of the executive periphery and the cerebral structures are uncoupled is conducive to the establishment of new reflex connections which are then consolidated during a course of treatment employing the device briefly described below.

The device is essentially a system of elastic traction bands built into the patient’s suit (or worn by the patients without any suit) and located between supporting elements which include shoulder caps, a broad belt in the lumbar region, kneecaps, and footwear. This device was developed in the late 1960s as a means of preventing adverse effects of weightlessness on cosmonauts such as decalcification of osseous tissue (which loses its strength) and atrophy of skeletal musculature consequent to weightlessness as a result of which the bony skeleton remains unloaded and skeletal muscles experience greatly decreased loads. A device of this type, called the Penguin suit, was used successfully for the first time by G. T. Dobrovolsky, V. N. Volkov, and V. I. Patsaev during their space flight on the Salut orbital station in June 1971.

The arrangement of the elastics that produce traction in the device resembles the topographic distribution of antagonistic muscles, i.e. predominantly of flexors and extensors, and also of muscles involved in rotary movements of the lower limbs and trunk. In addition, there are special traction bands capable of correcting positions of the foot, extension of the shoulder girdle, and the performance of other functions. The tractive force exerted by any of the elastics can be increased or decreased, as required, which makes it possible not only to impose axial (vertical) loading on the trunk and legs, but also to alter the posture and in particular to set up the necessary initial angles in the larger joints, and well as to flex and extend the trunk; it should be stressed that the axial loading along the vertebral column and lower limbs remains virtually unchanged as the posture is altered or the trunk is flexed or extended. Motor activities, including walking, of the person wearing this device are retained but made somewhat more difficult to perform, i.e. the device acts as an external elastic framework that only interferes with the execution of movements to some predetermined extent without limiting their amplitude.

Another device, designed specifically for clinical application and called the LK-92 Adeli Suit, is provided with a number of additional contrivances that take account of the special biomechanical characteristics of movements performed by patients with cerebral palsy. However, the forces developed in the Penguin and Adeli Suits as their main longitudinal elastics are stretched, have fairly similar values so that some parallels can be drawn in describing the use of these devices.

Although the total longitudinal load between the shoulder girdle and feet may reach 40 kg-wt, forces not exceeding 15-20 kg-wt are used in practice in patients with cerebral palsy.

A stress-strain diagram for the traction system of the Adeli Suit as a whole is shown in Figure 1.

The sigmoid shape of the curve which has an extended linear segment with a relatively small slope confirms that the axial loading will persist despite the performance of voluntary movements and the resulting alterations of angles in the major joints.

In space-flight practice, it is recommended to use, as the initial posture, angles of 135 degrees in the knee and hip joints. Figure 2.

It is such a position of the limbs which is known to be characterized by equilibrium of the antagonistic (flexor and extensor) muscles. Any movement that alters the initial posture (e.g., flexion, extension, or rotation of a limb) will be accompanied by additional loading of the muscles involved in a given motor act. This thesis is illustrated graphically in Figure 3 which shows the moments of forces arising as the angles in individual joints of a leg are altered; the flexion and extension in the hip and knee joints are accomplished from a neutral position at angles of 135 degrees. As follows from this figure, phenomena of hysteresis are detectable in the work of the elastics during the movements under consideration.

Of fundamental importance for the therapeutic process are both the energetic adequacy of the load created by the traction system of the suit and the optimal selection of the vectorial distribution of this load taking into proper consideration the particular pathologic motor stereotype that has developed in the patient over years of the disease and which includes habitual postures and muscular synergies and synkinesias. That the muscle groups are loaded adequately during the execution of voluntary movements using the devices considered here was confirmed by the following study. in healthy subjects, parameters of the bioelectrical activity of hip extensors were compared quantitatively as these muscles were overcoming the weight of a limb under natural conditions of terrestrial loading (in a supine position) and also when the subject was suspended using a system of special suspenders, i.e. under conditions of simulated hypogravity so that there was no need to overcome the limb's weight. The patterns of electromyographic (EMG) responses in these two cases of course differed, but when the traction system of the suit was in operation the EMG responses during experimental hypogravity were virtually identical to those recorded under conditions of natural gravity. This finding provides convincing evidence that the loading created by the device is adequate.

It is reasonable to expect that during the walking of a healthy individual or of a patient with unpaired motor activity under natural terrestrial conditions, the traction system of the suit will inevitably produce relative increases in the metabolic rate, pulmonary ventilation, heart rate, and in other concomitant phenomena as a result of the extra loading imposed by the system on the skeletal musculature Figure 4. It is interesting to note that a longitudinal load of the order of 14-16 kg-wt led by itself to a significant increase (by 0.2-0.6 kcal/min) in the metabolic rate in a healthy subject under resting conditions. Tests using an active treadmill moving at a speed of 5 km/h (120 steps per minute) showed that the metabolic rate increased to 6.2 kcal/min under an axial load of 25 kg-wt and to 7. kcal/min under that of 50 kg-wt.

Studies of motor-visceral relationships carried out by M.P. Mogendovich et al. revealed a correlation between the intensity of proprioceptive impulse inflows and the shifts in several vegetative (autonomic) functions; in particular, the responses of certain vegetative systems were found to depend on the character of actively maintained or passive postures and positions of a healthy subject in space.

The responses that occur under deliberately harsh experimental conditions (experimental hypokinesia of 4 or 5 days in duration) and that are elicited both by the simulated situation itself and by the compensatory mechanisms that come into play when the suit is worn, are of a generalized reflex nature, as is indicated by the following results obtained in tests on healthy volunteers. After the experimental hypokinesia mentioned above, the quantitatively recorded tremor was significantly increased in intensity in the subjects who had not been wearing the suit while decreasing by 2.7% in those who had. Similar results were obtained in tests using a squeeze dynamometer: after the hypokinesia, the subjects who had not been wearing the suit were able to hold the dynamometer for a shorter period of time in a position corresponding to 75% of the maximal effort, whereas an opposite result was shown by those who had been wearing the suit. An analogous tendency was noted in the healthy subjects with regard to the latency of the motor reaction of the right hand in response to an acoustic stimulus. It should be stressed here that the traction system of the suit does not exert any direct mechanical impact on the upper limbs.

Wearing the suit also affected markedly hemodynamic parameters. After five days of hypokinesia, for example, the pulse pressure was found to have decreased approximately by 57% (through a rise in diastolic pressure and a fall in systolic pressure) in healthy volunteers who had not been wearing the suit and only by 8% in those who had. Clearly, the orthostatic stability in the latter subjects remained at a higher level than in the former. Similarly, as shown by rheoencephalographic studies after the hypokinesia, the blood flow in the vessels supplied by the internal carotid artery remained virtually unchanged in the healthy subjects who had used the suit but was decreased by 22% in those who had not. The latter finding deserves special attention since maintenance of a satisfactory blood supply to brain structures during normalization of the motor stereotype is clearly of great importance in the treatment of cerebral disorders.

During simulated hypokinesia in a recumbent position, venous pressure rose markedly (from 103 to 147 mm water column on average) in the subjects who had not been wearing the suit while falling in those who had (from 144 to 112 mm. water column on average). This indicates that wearing the suit led to normalization of the vascular tone proper and, in all probability, ensured maintenance of the skeletal muscle tone, which is known to be a necessary condition for sustaining adequate venous blood flows.

Of special note are the results of a study in which the adverse effects of hypokinesia on the condition of osseous tissue and the ability of the loading suit to mitigate these effects were evaluated. It is common knowledge that an osseous tissue that does not bear weight undergoes decalcification and alters its mechanical characteristics. The efficacy of the suit was evaluated in healthy volunteers using a model of water immersion for five days, and the density of their osseous tissue was assessed roentgenophotometrically using a reference wedge made of aluminum alloy. It was found that whereas both spongy bone and long bones were decalcified to statistically significant degrees in the control volunteers who had not used the suit, the bones of those wearing it had undergone decalcification to only a minor and insignificant degree or, in most cases, had become even denser.

An understanding of the mechanisms through winch patients with neurologic disabilities benefit from the rehabilitative treatment described here can be gained by considering the residual stage of cerebral palsy.

Motor disorders in patients with cerebral palsy primarily stem from abnormalities arising in the functional antigravity system (FAS), i.e. are due to the impaired ability of this system to counter weights. In the presence of these abnormalities, disturbances in the reflex sphere develop – namely, the reduction of tonic reflexes characteristic of the neonatal period is delayed for several years, as is the establishment of righting reflexes, statokinetic reactions, and volitional motor activity. We assumed that such abnormalities in the FAS could be corrected by means of the Adeli device applied intermittently for a number of times per course of treatment.

Indeed, as shown by clinico-physiological correlations made in 32 cerebral palsy-affected patients aged 14 to 25 years, the use of this device had brought benefit to all of them regardless of the form of the disease, whereas their previous treatments by other methods had to be discontinued because they had failed to improve the patient's condition over a number of years or, at best, had been capable of only sustaining the particular the first few years of life.

A course of treatment using the adeli suit consisted of 20 to 25 sessions, lasting 30 to 60 minutes each. After 10 or so of such sessions or by the end of one treatment course, pathologic synergies disappeared or diminished, new opportunities for static postures, locomotion and the execution of voluntary movements appeared, and hyperkinesias and ataxias were less marked in most of the patients; later, dysartrias also became less pronounced.

To improve and consolidate the results, further courses — up to four or even more in some cases had to be administered depending of the severity of the disease. After these courses, 90% of the patients were able to walk unaided and perform correct stepping movements and showed improvements in extrapyramidal and cerebellar symptoms [Table 1]; the dysarthrias disappeared [Table 2]. The best results were attained in patients with hyperkinesias or with the atonic-astatic form of cerebral palsy, i.e. with conditions that are considered to be virtually incurable in teenagers.

The question arises, how were the improvements mentioned above brought about if they were really due to the method of rehabilitation used?

It is a firmly established fact that the prenatal development of the brain and spinal cord is greatly influenced by afferent impulses from the system of muscles, joints, and ligaments and from receptors of the vestibular system. When afferent impulse flows of any modality, but primarily of proprioceptive and vestibular modalities, are impaired, this leads to pre- and postnatal disorders of the nervous and locomotor systems.

Studies carried out in the Department for Rehabilitative Treatment of Children with Cerebral Palsy (Research Institute of Pediatrics, Moscow) have also shown that considerable disturbances in the activity of the vestibular system can. be caused by damaging factors acting during the period of intrauterine development, and that these disturbances are manifested in patients with cerebral palsy as motor disorders involving all levels at which movements are regulated and shaped.

Structures of the vestibular system constitute one of the principal projection areas for ascending, flows of afferent impulses, particularly from the transverse joints of the foot (Shopar and Lisfrank), which is of particular significance in diseases of the locomotor system and in the development of its deformities. Therefore, many of the motor and vestibular reactions we have observed are interdependent. In particular, the main manifestation of vestibular function amenable to study, namely the vestibular nystagmus generated during rotational tests and recorded by means of electronystagmography, is a statokinetic reaction of the striated oculomotor muscles, and many of the normal and pathologic phenomena consistently associated with vestibular nystagmus can be extrapolated to the activity of skeletal musculature.

The studies performed in patients with cerebral palsy during their treatment using the Adeli Suit furnished clear evidence for a progressive normalization of the age-related development of the vestibular system in these patients. Thus, the imbalance in the paired interaction of the labyrinths decreased or, in some cases, virtually disappeared, which was expressed clinically in markedly decreased asymmetries of statokinetic responses and in partial normalization of muscle tone. The relationship between the reactions of otolithic organs and semicircular canals was gradually returning toward normal, which, as a rule, was most conspicuous after the second or third course of treatment. The semicircular canals began exhibiting a greater autonomy in their activity when otolithic reactions were provoked — for example, in a test with eccentric rotation of the patient, and this also was reflected in improved muscle tone (in decreased spasticity and rigidity).

A decrease in the frontal swinging during walking typically observed in patients with cerebral palsy, which stabilized, naturally enough, the position of the patient's center of masses, occurred at a time when asymmetries of the vestibular nystagmus were becoming smoothed out and its dysmetria had decreased. These effects correlated, to a degree, with a decreasing severity of the hyperkinetic syndrome and with decreases in the metabolic rate and increases in the walking pace.

As in our previous study, we were able to predict to some extent the efficacy of subsequent courses of rehabilitative treatment by noting the features of vestibulo-oculomotor responses and especially by comparing characteristics of the vestibular nystagmus before and after a treatment course.

An indirect confirmation that the vestibular function, which is directed, in particular, at ensuring smooth ambulation by evening out the trajectory along which the body's center of masses moves, is returning toward normal in the process of treatment is provided by the observed time course of changes in the distribution of contact pressures exerted by the foot and in the involvement of its parts in the supporting reaction during the phase of rolling over in the interval from the start of the anterior push-off to the end of the posterior push-off.

The studies have demonstrated that the establishment of appropriate functions of the vestibular system and of the antigravity system as a whole under the influence of the afferent proprioceptive traffic developing as a result of wearing the Adeli Suit, exerts harmonizing effects on many other functional systems of the body – by stimulating postnatal development of the central nervous system (CNS) and thereby normalizing motor activity, speech, and, in large measure, intelligence.

Thus, the formation of the antigravity function has been shown to be interrelated with processes by which background bioelectrical activity of the brain is generated and sensory information is received and processed, and with the activity of the immunocompetent system.

Patients with cerebral palsy display markedly decreased functional capabilities not only of the motor cortical areas but also of the cortex as a whole, which is manifested in altered bioelectrical activity of the brain.

Serial electroencephalograms (EEG) taken from adolescents in the course of their treatment with the Adeli device showed positive changes of varying degrees — in some cases as early as after the first session. EEG studies have indicated that the positive influences exerted by the new method on functional activity of the brain are of the same type in most patients and occur in two stages. The first stage, which usually sets it in the middle of the treatment cycle, involves suppression of the pathologic activity displayed by subcortical structures, while the second stage, observed at the end of the cycle, is characterized by a greatly improved bioelectrical activity of the brain associated with enhanced functional activity of the cortex, a greater regularity of the major cortical rhythm, and with a decreased asymmetry in, or normalization of, the distribution of biopotentials over the convex surface of the cortex.

Studies on patients admitted for repeated treatment courses 3 to 8 months after completing previous courses showed that the EEG improvements attained during the latter courses still persisted. This could be taken as evidence that the functioning of thalamocortical connections had been firmly established and than control over the underlying structures had. not been lost.

Taken as a whole, EEG studies indicate that treatments using the Adeli Suit bring about a substantial reorganization of bioelectrical activity at the cortical and subcortical levels, apparently by causing formation of new functional connections that are realized through expansion and partial normalization of the patterns of movement regulation.

In conclusion, the clinical observations and results of neurofunctional studies presented above demonstrate the desirability, from a pathogenic viewpoint, of correcting the afferent impulse traffic of predominantly proprioceptive modality to CNS structures and suggest that the search for new applications of the method by which dynamic proprioceptive correction of motor and speech disorders is effected with the Adeli Suit can yield rewarding results in the areas of both pediatric and general neurology.

Table 01: Levels of Motor Development in Children with Cerebral Palsy Before and After Applying the Method of Dynamic Proprioceptive Correction (1 to 4 Courses of Treatment using the Adeli Suit)

No	Form of disease (diplegia)	P	Level of Motor Development									
			1st Level		2nd Level		3rd Level		4th Level		5th Level	
			B	A	B	A	B	A	B	A	B	A

1	Spastic	18	–	–	1	–	5	2	7	9	5	7
2	Hemiparetic	5	–	–	–	–	–	–	1	–	4	5
3	Hyperkinetic	9	3	1	1	1	2	–	3	4	–	3
4	Atonic-astatic	2	2	–	–	–	–	–	–	2	–	–
	Total	34	5	1	2	1	7	2	11	15	9	15

P – Number of Patients; **B** – Before Treatment; **A** – After Treatment

1st Level: the patient cannot move unless aided by somebody else.
2nd Level: the patient can move supporting himself on a wheel chair or walker.
3rd Level: the patient can move supporting himself on crutches or walking sticks.
4th Level: the patient can walk unsteadily on his own for short distances (up to 50 meters) with a deformed gait.
5th Level: the patient can walk steadily for distances of more than 50 meters with a deformed gait.

Table 02: Speech Function in Children with Cerebral Palsy Before and After Applying the Method of Dynamic Proprioceptive Correction (I to 4 Courses of Treatment using the Adeli Suit)

No	**Form of disease (diplegia)**	**P**	**1st Level**		**2nd Level**		**3rd Level**		**4th Level**	
			B	**A**	**B**	**A**	**B**	**A**	**B**	**A**
1	Spastic	18	1	–	2	1	2	2	13	15
2	Hyperkinetic	9	4	2	3	2	2	4	–	1
3	Atonic-astatic	2	2	–	–	1	–	1	–	–
	Total	29	7	2	5	4	4	7	13	16

P – Number of Patients; **B** – Before Treatment; **A** – After Treatment

1st Level: Severe disartria
2nd Level: Moderate disartria
3rd Level: Mild disartria
4th Level: Near-normal speech