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Functional conditions of three-dimensional correction of side curvatures of the spine

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Authors' Contribution:
A – Study Design
B – Data Collection
C – Statistical Analysis
D – Data Interpretation
E – Manuscript Preparation
F – Literature Search
G – Funds Collection

Key words: *scoliosis, functional correction, correction optimization, children*

Abstract

Background: *This paper sets out to present theoretical and methodological premises for the therapeutic mode of conduct which utilizes FED and PNF improvement methods complemented by introduction of correctional re-education basing on the biofeedback mechanism.*

Material/Methods: *Authors develop and present an original mode of treatment of children with the SCS, which can be divided into the following stages and targets:*
1. Elimination of biomechanical pathologies of the passive stabilizing. 2. Restoration of the structure and function of local muscles and balance among muscles from the first and second reference arrangement and structures around the spine, both on the concave and convex side. 3. Posture re-education, which consists in the combination of three-dimensional active and passive correction of the spine with proprioceptor stimulation techniques, accompanied by the use of replacement feedback.
In order to implement the proposed treatment programme a device called "Skol-as" was built. "Skol-as" enables a simultaneous three-dimensional action on the passive and active stabilizing mechanisms and the functional structures of the Central Nervous System.

Results: *Exchanged information constitutes a replacement feedback which enables additional transfer of information on the position of the body to the CNS. Therefore, this constitutes a particular complement to the proper proprioception stimulated by the structure and functionality of the "Skol-as" device, which provides exteroceptive stimuli offering the image similar to the correct, spatial layout of the body.*

Conclusions: *The suggested method – which accommodates the latest trends in SCS treatment – may and should be applied practically at each stage of scs development. This gives both the child and the parents or the therapist anopportunity to control the improvement process. Appropriate application of the suggested method and the "Skol-as" device offers children efficient self-control of their posture, which is much easier after the application of appropriate training suggested in the method. This therapy enables not only the strengthening and changing the functioning scope of relevant muscles but also affects the mental perception and feeling of muscle tensions which leads to proper self-image and appropriate control of bodily posture.*

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Introduction

Research into the physiological and biomechanical considerations justifying certain treatments of back pain and side curvature of the spine (SCS) has been underway for many years. Opinions on this subject vary significantly. This is due to the ever expanding knowledge on this topic, which results from extensive research carried out in many scientific centres.

Nonetheless, the causes of the SCS still have not been identified. In effect, therapists have noticeably different approaches to the spine curvature treatment. For example, F.S. Sastre ascribes the key role in the development of the SCS and pathological changes in the passive stabilizing mechanism to the epiphyseal (growth) cartilage of the vertebral body, which enables longitudinal growth of the vertebra, and the neurocentral cartilage, which enables growth of the lateral part of the vertebral body and the front part of the vertebral arch [1]. Development of structural changes in vertebrae during childhood and adolescence, such as asymmetrical growth of the epiphyseal cartilage leads to vertebral wedging and unevenness of the vertebral arch, elongated on the concave side due to the neurocentral cartilage growth results in rotation of the vertebra. Basing on these premises, Sastre developed a methodology of FED (Ficsatio – Elongatio – Derotatio) therapy, which consists in relieving the compressed cartilage, basing on the assumption that 'if dynamic and asymmetrical compressing forces can cause development and exacerbation of osseous deformations within the period of bone formation, application of other forces of opposite directions should supress the initial deformation process and lead to normalization' [1, 2].

A completely different approach to the SCS therapy is represented by followers of the muscle tension disorder theory. Such tensions often occur in effect of reflexive stimulation (sometimes of unknown origin), transferred from the central nervous system (CNS). Basing on this theory, to treat scoliosis, therapists utilize one of the rehabilitation methods, which is normally used for re-education in the central and the peripheral nervous system diseases and disorders – *proprioreceptoric neuromuscular facilitation* (PNF) [3].

The two different forms of improvement briefly presented above focus on the disorders of either the passive stabilizing mechanism [1] or the active stabilizing mechanism, which stem from pathology in the central or peripheral nervous system [3], and they constitute completely different approaches to the SCS therapy. Therefore, an assumption can be made that unification of the spine curvature improvement method is not likely in the near future.

Aim and method justification

This paper sets out to present theoretical and methodological premises for the therapeutic mode of conduct which utilizes FED and PNF improvement methods complemented by introduction of correctional re-education basing on the biofeedback mechanism.

According to the law of biomechanics, it should be assumed that the functional features of the spine will stay unaffected only if the passive and active stabilizing mechanisms remain in the state of symmetrical tension. This inter-dependence may be presented graphically (Fig. 1).

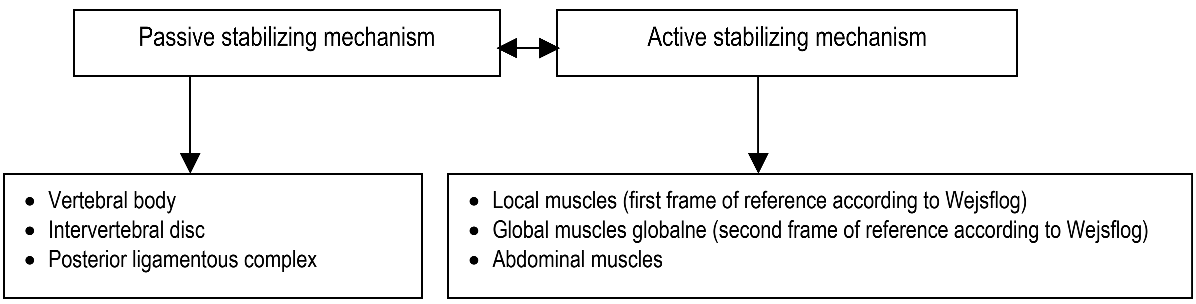

Fig. 1. Inter-dependence in the spine stabilizing mechanism

However, in case of pathological changes, e.g. SCS, this symmetry is distorted. This is a complex of inseparably connected causes and effects which stem from symmetry distortion between the passive and the active stabilizing mechanisms and the neural control system, which is demonstrated in Figure 2.

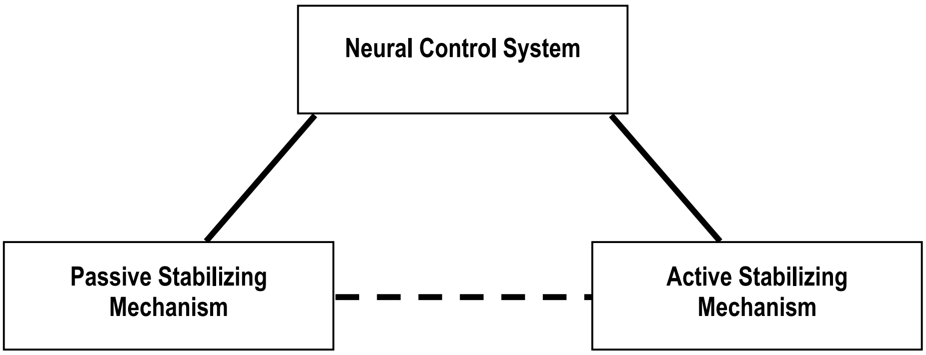

Fig. 2. The inter-dependence diagram of cause and effect relationships in balance maintenance in the spine stabilization

In the passive stabilizing mechanism, deformations of the vertebral body (the Wolff-Delpech law), and intervertebral facets (the Huter-Volkmann law) occur. Furthermore, a variable course of ligaments is also observed, which probably induces the displacement of the *nucleus pulposus* towards the convexity of the curvature. The described biomechanical conditions significantly affect functional changes in the passive stabilizing mechanism. This is manifested by the amplification of forces which stretch the soft elements adjacent to the spine, such as joint capsules or muscles on the convex side of the curvature and by a simultaneous reduction of these forces on the concave side of the curvature. This triggers variation in gravitational pressure forces on the articular surfaces of intervertebral facets and vertebral bodies. This micro-gravity which occurs on the concave side of the curvature may have an influence on further pathological changes (e.g. in neural control) which facilitate the development of curvature.

In the active stabilizing system, atrophy and increased fatigue of muscles from the first reference arrangement (local) (the multifidus muscle) is observed. In the case of global muscle – the second reference arrangement (the *erector spinae*) hypertrophy and a decrease in fatigue is observed [4]. Zetterberg et al. [5] highlight the disappearance of tonic muscular fibres (type I) and the increased occurrence of fibres of type IIb and IIa on the unburdened side of the spinal curvature. On the concave side, on the other hand, opposite relations between the quantities offibres of type I, IIb and IIa are observed.

The neural control system may itself be a source of distortions in the active stabilizing mechanism. According to some scientists, distortions of muscle tension balance are derivative of hitherto uninvestigated changes in the central nervous system [6]. Damage to the central and peripheral nervous system is accompanied by muscle debility. This results in loss of extra- and intramuscular coordination. The long lasting pathological process leads to changes within fibres, their length, cross-section, quantity and type [7].

These changes in the structure and function of the muscle prevent its normal activity as the basic conditions are not met, such as:

1. Limited proper muscle stimulation as the transfer of stimuli from the nervous system.It is highly probable that micro-gravity in the passive stabilizing mechanism induces conduction changes in the so-called gamma control system [4]. Konemura et al. [8] believe that limitation of the influence of gravity decreases the activity of gamma motoneurons.
2. Proper structure and layout of muscular fibres which enable contractility and elasticity. Biomechanical factors which induce SCS create different conditions for the work

(contraction) of muscles on the two sides of the spine – imbalance of the leverage occurs [9].

3. Proper layout, length and conduct of tendons. If children with SCS do not meet this condition, the development (growth) asymmetry is aggravated.
4. Proper processes of creating, storing and utilizing energy in muscles. Asymmetry of blood circulation, oxygen supply and unbalanced stress load of the muscles results in weakening their metabolic efficiency.

In consequence of the changes, i.e. improper length and activation of the muscles (disorder in the length-tension relation), force vectors of the synergists and antagonists which work around the joints are not balanced. The lack of balance leads to the shift of the joint rotation axis. A new rotation axis is created, which is placed eccentrically to the physiological one [9].

Continuous, asymmetrical influence of gravity on the shifted joint axes induces creation of forces which rotate vertebrae and aggravate the lateral curvature of the spine. These biomechanical and functional processes, which trigger the three-dimensional curvature of the spine, activate micro-gravity on the convex side of the intervertebral articular surfaces.Reducing the gravitational sensory stimulation impairs the function of the gamma system, which leads to structural changes in muscles from the first reference arrangement.

This shows that there is a simple relationship between active muscle tension and the shape of the spine. Any variation of the shape of the spine will trigger changes in the active stabilizing mechanism and the neural control system. If muscle tension changes in result of the neural control system disorders, the shape of the spine will change.

Material and method

The presented static and dynamic disorders lead to permanent changes in the length of muscles and shifted position of articular surfaces. The altered anatomical conditions affect the stimulation of the proprioceptors which are sensitive to shortening and elongation (expansion) of particular muscles. The altered data from the proprioceptors are transferred to the central nervous system (CNS) and compared with the program (pattern) encoded there. If the pathologically changed influx of data continues for a longer period, a new habit (new pattern) for improper posture will develop [10].

In cases where the aetiology of the SCS is unknown, it cannot be clearly stated what is a cause and what an effect of the presented phenomena in the chain of balance disturbance among the three components (Fig. 2). We believe that the three elements, changes in the passive and the active stabilizing mechanisms and the habit of bad posture, which is a symptom of transmission disturbance of data on the linear and angular position of joints and muscles from the proprioceptors, are equally important and closely connected, both in the biomechanical and functional sense. Structural dysfunction hinders a child from adopting a correct posture and prevents optimal movements. Neuro-muscular dysfunction, on the other hand, causes improper burden of the joint system, which often leads to a structural dysfunction. The inter-relation of the dysfunctions is clearly underscored by the Molier principle, which states that the entire static and dynamic human system, including the spine, constitutes one functional unity [10].

These premises were an inspiration to develop and present an original mode of treatment of children with the SCS, which can be divided into the following stages and targets:

1. Elimination of biomechanical pathologies of the passive stabilizing system which aggravate the curvature progress.
2. Restoration of the structure and function of local muscles and balance among muscles from the first and second reference arrangement and structures around the spine, both on the concave and convex side.
3. Posture re-education, which consists in the combination of three-dimensional active and passive correction of the spine with proprioceptor stimulation techniques, accompanied by the use of replacement feedback which enables programming afresh and creating a new pattern of proper posture.

Legitimacy of such gradation was confirmed by the results of tests conducted by Nowotny-Czupryna et al. [11], which confirm that:

a) the strength of the global muscles is unrelated to the size of the SCS, the location and size of the original curvature or the degree of treatability. Evidence is decisive that despite significant muscular strength and endurance, improper posture is adopted, and curvature progresses despite treatment [11].
b) The muscles from the first reference arrangement play a more important role as they donot only counteract gravity but also have a significant impact on the posture.
c) Maintenance of the optimal spinal system is rather related with the undisturbed habit of proper posture.

The key argument for comprehensive treatment of the passive and active control system combined with the re-education of posture is the opinion of Nowotny, who believes that: “possibility of adopting any posture depends not only on the unimpaired supporting capability of the spine but also on the broadly defined efficiency of the neuro-muscular system. However, this efficiency cannot be narrowed down to counteracting the gravity and maintenance of erect posture. The function of these muscles must be also perceived in context of their proper interaction” [10].

According to Zielke and Morscher from the Centre of Scoliosis Treatment in Bad Wildungen (Germany) “individual correction of scoliosis deviations with the mere use of free exercise is impossible” [12].

In order to implement the proposed treatment programme a device called “Skol-as” was built (Fig. 3A and B). “Skol-as” enables a simultaneous three-dimensional action on the passive and active stabilizing mechanisms and the functional structures of the Central Nervous System.

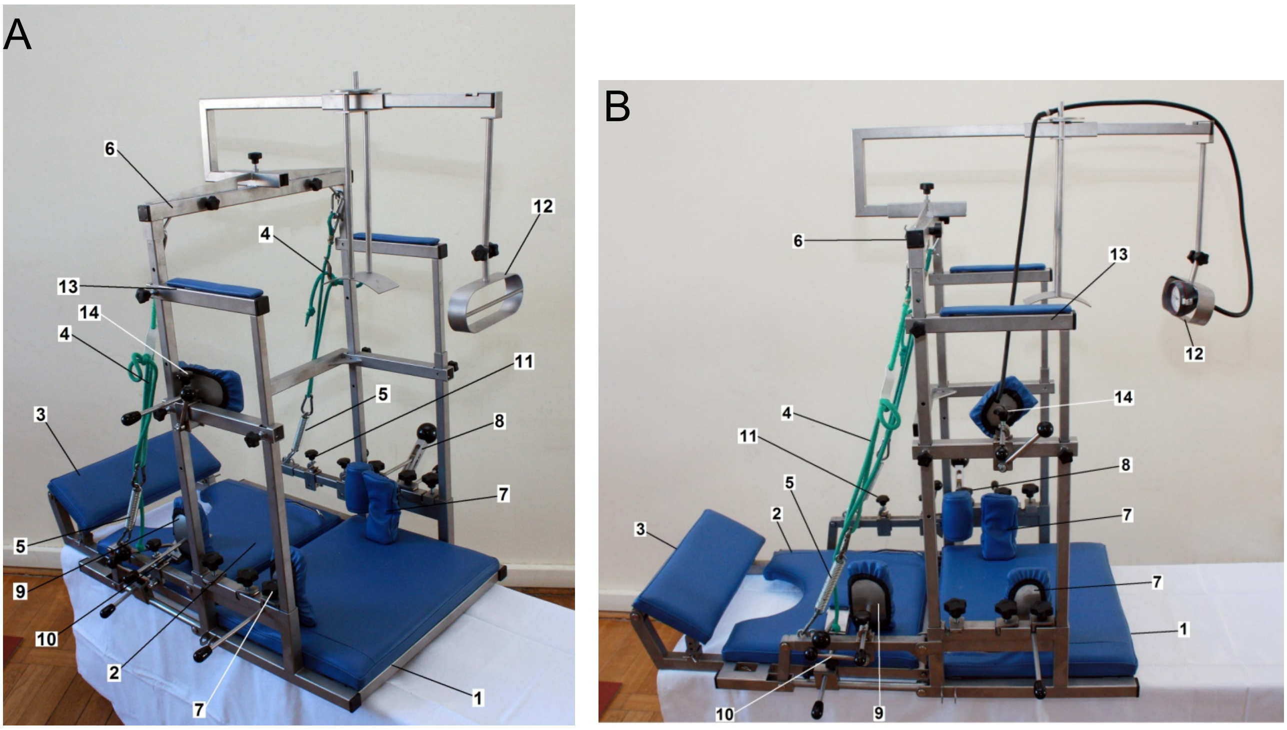

Fig. 3A–B. Description and diagram of the device construction (1. device base, 2. movable part, enables upward and downward movement, 3. headrest – may be removed in the case of exercises on the cervical part of the spine, 4. lines of 6-8 mm in diameter, 5. springs, 6. the so-called gate – used also in re-education exercises – sitting position, 7. asymmetrically positioned pads to stabilize the pelvis, 8. pad for correction of the lumbar section, 9. pad for correction of the thoracic section, 10. pad to counteract the rotation of the thoracic section 11. stabilizing pad, installed near the armpit, 12. manometer holder, 13. frame for exercises in a sitting position, 14. pad for correction of the thoracic section in a sitting position [9]

Results

Restoration of physiological balance among the three constituents enables creating amotor habit which is conducted in three phases: generalization, concentration (with sub-phases: repression and consolidation) and automation. One must remember to eliminate previously developed and consolidated disorders of the motor function, which resulted from:

- disorders of the supporting system, i.e. bones, joints and ligaments,
- improper function of the muscles which hold the movement supporting element – muscles of the first reference arrangement are most relevant here;
- improper neurophysiological motor control, both on the peripheral level – the afferent or efferent conduction, and on the analyser level.

Suggested methodology of correctional treatment and its justification

Stage 1.

The device is comprised of a system of pads and springs which enables three-dimensional correction of the passive stabilizing system through:

1. Reducing side curvature of the spine in a passive way (frontal plane), with the use of a recliningposition and pressure of the cushions withconscious, controlledmuscle tension.
2. Reducing the rotation of the thoracic section of the spine with the use of the so-called thoracic counter-rotating pad, positioned under the rib hump (10). The lumbar vertebra are corrected by active and passive counter-rotation of muscles from the first reference arrangement, aided by the lumbar counter-rotating pad.
3. Correction in the sagittal plane, which reduces shearing forces affecting the intervertebral facets, achieved in the exercise initial position combined with tension of global and local stabilizing muscles.

   Additionally, “Skol-as” is used for adopting corrective and hyper-corrective positions of the body in order to:

   - reduce the pressure on the epiphyseal cartilage which impedes the development of the vertebra on the concave side of the curvature;
   - stimulate the neurocentral cartilage on the convex side;
   - increase the elasticity of structures around the spine on the concave side;
   - increase the intervertebral mobility, which improves lung ventilation;
   - unburden intervertebral joints.

In the “Skol-as” device, a child lies on its back, with its torso, pelvis and head fully supported. Therefore, muscles of the first and the second arrangement frame are relaxed. Furthermore, reflexive tensions used to counteract the gravity, keeping specific posture and spatial balance are switched off. In effect, the forces used to counteract rotation and correct side curvature do not have to be big to obtain the expected results.

Stage 2.

Once the three-dimensional correction of the passive stabilizing mechanism is achieved, the active stabilizing mechanism is stimulated.

a. The purpose of stimulation is to restore the impaired function of the muscles from the first arrangement frame which, along with the muscles from the second arrangement frame, are responsible for spine stabilization, which prevents development of curvatures in the sagittal and the frontal planes. These muscles also counteract gravity and have a significant influence on adopting bodily posture.Therefore, the opinion that the main focus of SCS treatment should be shifted from exercises strengthening the muscular corset to local muscles from the first arrangement frame [10] is gaining more and more supporters.

   It should be noted that the strength of the multifidus muscle (first arrangement frame) will not recover if specific exercises focused on its reactivation are not performed [13]. In turn, Mc Gill et al. [14] believe that if local muscles show symptoms of functional impairment, isolated exercises of global muscles will not compensate for the deficiency in the muscular control of the spine. This is confirmed by other tests which show that asymmetrical or symmetrical strengthening exercises do not correct dysfunctions of the local stabilizing system. Exercises of local muscles, on the other hand, remove dysfunctions in the local and global stabilizing system [15]. The thesis on the role and function of the local muscles was confirmed by the research conducted by Tylman [6] on elastic models of the spine and also during surgeries of children with side curvature of the spine. Tests with the use of needle electrodes showed a reducedreflexive response for the muscle group located on the convex side of the curvature and increased response on the concave side [16]. Malawski [17] confirmed and documented histopathological changes in muscles from the first arrangement frame inchildren with the side curvature of the spine.

Local muscles (first arrangement frame) which stabilize the lumbar section of the spine comprise: transverse abdominal muscle, multifidus muscle, lumbar (the rear part), *quadratuslumborum* (the medial part), *iliocostalis* (the lumbar part), and *longissimus* (the lumbar part). These muscles work when they are stimulated by unfolding, or contract only with other muscles from the second arrangement frame. The suggested SCS treatment methodology involves stimulation for contraction of the deep muscles from the first arrangement frame located on the convex side of the curvature during stabilizing exercises.

The therapy utilizes the principle of one-way static and dynamic interrelation between the stabilizers from the first and the second arrangement frame, which states that one-sided contraction of any muscles (from the second arrangement frame) induces simultaneous activation of spine stabilizers (first arrangement frame) but never the other way around [18].

In practice, the exercise is conducted in the following way:

- a child lies in the "Skol-as" device,
- a pad which counteracts rotation, e.g. lumbar, pushes the convex side of the curvature until complete correction of the spine is obtained,
- the child pushes the string with its leg to activate also the muscles from the first arrangement frame on the convex side of the curvature,
- expansion with the rotation counter-acting pad lasts 15 seconds. After this time, pressure is released and the child is required to maintain the corrected posture with the use of muscles from the second arrangement frame.

Guyton [19] believes that "to bring the muscle contraction closer, sensitivity of muscle spindles must be increased through the gamma system in order to maintain the necessary, reduced length of fibres". This results in increased tension of these muscles.

Each element of the presented exercise is conducted in a closed kinematic chain.These exercises do not aim at rebuilding muscle mass but at restoration of the neuro-muscular control, especially for the muscle group from the first arrangement frame. These conditions will be met thanks to an acknowledged therapeutic system – SET (Sling Exercise Therapy) which is based on exercises in closed kinematic chains.

b. **Before starting exercises which create conditions for recreation of the muscle structures and functions from the first arrangement frame on the convex side, the contracted muscles from the first, second and third arrangement frames must be relaxed.** Such relaxation of contracted muscles is obtained by introducing post-isometric relaxation in appropriate starting positions.

Another way to expand muscles or structures around the spine is using the "Skol-as" device to keep the child for a dozen-or-so minutes every day in a position of maximal expansion of muscle groups or a particular section of the spine. Restoration of balance between the concave and the convex sides is related to the distribution of compressing and expanding forces. Children with SCS have stronger pressure on vertebrae on the concave side and smaller pressure on the convex side. The distribution of expanding forces is opposite. These relations, according to the Wolff-Delpech principle, affect vertebrae wedging and condition the functions of proprioceptors, making the restoration of properneuro-muscular activity impossible. Restoration of neuro-muscular activity on the concave side is a necessary condition to recreate the proper posture pattern.

Stage 3.

In SCS therapy, the nervous system is treated as the system which controls the bodily posture in shaping the proper posture habit. Recreating the habit of proper posture requires proper build of bones and joints and proper functioning of the muscular system.

Attempts are made to shape the two features at the initial stage of the therapy. They constitute a point of departure for the entire working plan, which is ultimately aimed at creating a new, proper posture habit, undisturbed by the pathology of the passive and active stabilizing mechanism and the nervous control system.

Therefore, the aim isto use the flow of proper information (stimuli) from receptors located in muscles, joints, joint capsules, ligaments connected to the CNS, through to the effector, to create an appropriate, required mechanism of intended movement. Tests on animals have shown that in conditions of released tension (microgravity, lowered burden of joint receptors) the number of joint mechanoreceptors connected with the gamma system decreases [8]. The exercises conducted in the "Skol-as" device create conditions for stimulation of these structures. The focus is not only on the proprioception (information from the proprioceptors) but also on the stimuli sent to the CNS from the equilibrioception organ and the exteroceptors.

In the next stages of the suggested re-education process, exercises are conducted in sitting, and then in a standing position. In exercises, a child should correct the position of the spine following oral, haptic and visual instructions provided by the instructor. Exchanged information constitutes a replacement feedback which enables additional, exteroceptive transfer of information on the position of the body to the CNS. Therefore, this constitutes a particular complement to the proper proprioception stimulated by the structure and functionality of the "Skol-as" device, which provides exteroceptive stimuli offering the image similar to the correct, spatial layout of the body.

Conclusions

In conditions of current civilisation, children and adolescent people are subject to hypokinesia due to prevalent computerization, motorization and increased interest in pastimes unrelated to sport. Despite the growing awareness of dangers connected with SCS and common access to information on preventive treatment, the mentioned civilisation-related factors induce the increase in SCS occurrence. General physical activity (daily, lasting many hours) is dying out among children.

The suggested method – which accommodates the latest trends in SCS treatment – may and should be applied practically at each stage of SCS development. This gives both the child and the parents or the therapist an opportunity to control the improvement process. Appropriate application of the suggested method and the "Skol-as" device offers children efficient self-control of their posture, which is much easier after the application of appropriate training suggested in the method. This therapy enables not only the strengthening and changing the functioning scope of relevant muscles but also affects the mental perception and feeling of muscle tensions which leads to proper self-image and appropriate control of bodily posture.

In conclusion:

1. The three-dimensional correction of the spine is the most comprehensive method of SCS treatment.
2. The presented method and the "Skol-as" device create optimal conditions for effective SCS treatment.

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