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INFORMATION TECHNOLOGY "MYOBALANCE-STIMUL" FOR DIAGNOSTICS AND CORRECTION OF SCOLIOSIS POSTURE DISORDERS

Theoretical and practical principles of synthesis of the information technology for diagnostics and personalized correction of scoliosis posture based on control of balance of muscles activity that form the spine vertical orientation depending on a state of balance have been considered. The technology is implemented by the "MYOBALANCE-STIMUL" computer complex. This complex consists of the two-channel programmed myostimulator "MyoBalanceStimul" or an improved two-channel myostimulator "MyoBalanceStimul-2", with an expanded range of myostimulation programs, and a personal computer. The usage of two correction methods, electromyographic feedback and programmed stimulation, the display of the balance of symmetrical back muscles activity on the indicators of the stimulators and on the computer contribute to personalization, stability of correction, assessment of its effectiveness, strengthening of the "muscle corset", prevention of the development of complications.

Keywords: scoliosis posture, diagnostics, personalized correction, electromyographic feedback, programmed myostimulation, computer complex.

Introduction

Restorative treatment and prevention of postural defects is one of the most topical problems of modern orthopaedics. This is related not only to with the prevalence of the disease, especially among schoolchildren, students and office workers, which is caused by the spread of computers and decreased motor activity, but also to the difficulties with timely diagnostics and treatment of a patient [1, 2]. There are two groups of posture disorders, one relating to the changes in physiological curves in the sagittal (anterior-posterior) plane and spine curvature in the frontal plane (scoliosis posture, scolio-sis) [3]. Research considered in the paper relates to the diagnostics and correction (treatment) of the scoliosis posture and initial stages of scoliosis.

The purpose of the paper is to consider the theoretical principles of the synthesis and technical implementation of the new information technology for the correction of scoliosis posture disorders, which, depending on the diagnostics of disorders, carries out personalized correction of the balance of muscle activity, muscle tone, strengthening of the "muscle corset" that form and maintain vertical orientation of the spine in the frontal plane.
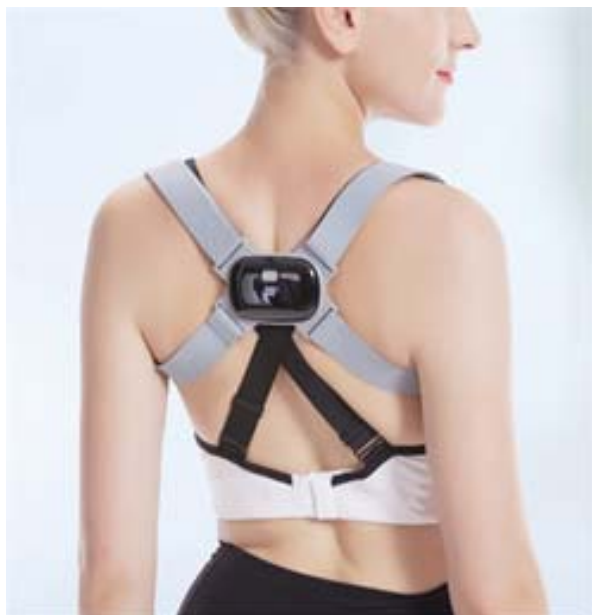
Fig. 1. An updated posture corrector POSTURE TRAINER (Smart Sensor Orthosis)

Research in the Field of Treatment of Scoliosis Posture Disorders

The conservative methods of treatment of postural scoliosis and initial stages of scoliosis include the usage of physical therapy, massage, swimming, electrical stimulation of muscles at rest [4], as well as the usage of corsets of various modifications. However, physical therapy, massage and swimming require long-term usage and does not enable in a short time to strengthen the muscle corset", which prevents the development of complications. It should be noted that electrical stimulation of muscles at rest creates a "muscle corset" quite quickly, but since it is separated from the motor act, it doesn't doesn't promote stability of the correction.

The most widespread and influential method for diagnostics and correction of posture is the biological feedback method (biofeedback). The biofeedback method implements the principle of a "physiological mirror". The role of "mirror" is performed by special equipment and software, which helps the patient to get the opportunity to see and hear his physiological properties. Electromyogram, pressure, impedance and vibration are used as tools to provide the information on functions activity [5-8].

E.g., an updated posture corrector Posture Trainer (Smart Sensor Orthosis) uses vibration as an information signal of biofeedback. Such a corrector contains a smart sensor that will remind with a vibration signal on incorrect posture vertical curvature of the spine (Fig. 1) [8].

If the patient wears such a corrector for a certain period of time, he develops muscle memory, and further even without a simulator the correct posture can be maintained. The corrector is suitable for adults and children, as its size is adjustable.

Therefore, the biofeedback method is a modern device-based method for children and adults treatment of scoliosis. The method has gained popularity for children treatment, because it is realised in a playful way.

The advantages of the biofeedback method:
— enables quantitative assessment of diagnostics and treatment;
— a personalized approach to each patient;
— high effectiveness;
— the method is combined with all types of medical procedures and has no absolute contraindications to use.

Among the biofeedback methods, the electromyography (EMG) feedback attracts special attention. The objective registration of EMG signal from the studied muscles, the processing and output of the signal in an acceptable to a patient form help to develop the skills of self-control and self-regulation of activity of the muscles that are involved in the formation and correction of posture, in particular vertical orientation of the spine.

In the conditions of pathological processes of spine deformation, there is an uneven decrease in the functional attributes of the muscles on the right and left sides of the body. The EMG studies showed that the stretched muscles of the convex side generate bioelectric activity of higher amplitude than the muscles of the concave side, which are in a state of relative contracture. This helps for the spine bend in the direction of weakened muscles and further progression of spine's deformation [4]. Therefore, the EMG signal from the symmetrical back muscles can be an informative indicator of diagnostics for disorders of vertical orientation of the spine, as well as an indicator for the disor-

ders analysis. In addition, the EMG signal can be not only a material for the disorders analysis, but also a tool for correction and assessment of its effectiveness. Therefore, it is theoretically justified to use the EMG feedback method for the diagnostics and treatment of scoliosis posture disorders based on voluntary contractions of the relevant muscles by the patient ("active correction" method). Such a method has been used in our previous research [9].

Computer Complex "MYOBALANCE"

During the first stage of research, the information technology for diagnostics and correction of posture disorders, vertical orientation of the spine in the frontal plane, was developed using the EMG-feedback (visual and audio) method. This technology is implemented by the "MYOBALANCE" computer complex. The technical subsystem of the complex consisits of two-channel functional and technological module "MyoBalance". The structural-functional models of the "MYOBALANCE" complex and two-channel functional and technological module "MyoBalance" have been developed. The pilot studies have been carried out to identify informative indicators for activity balance and tone of spine muscles that form the vertical orientation of the spine based on "MYOBALANCE" complex [9].

Functional and technological module "MyoBalance" provides the following functions:

▪ reception and amplification of EMG signals of muscles by two channels in the registration range of 20-1000 Hz in real time mode;

▪ light and sound control of the current EMG level;

▪ normalization of amplified analog EMG signals' level to transmit them to the linear inputs of a computer's sound card and signal transmission to the module from the computer through the sound card's linear outputs;

▪ the transmission of an analog EMG signal from two channels to the computer's USB port through an external USB audio adapter.

For operative monitoring of the EMG signal's current level, the signal's light indication with the help of linear indicators separately for each chan-
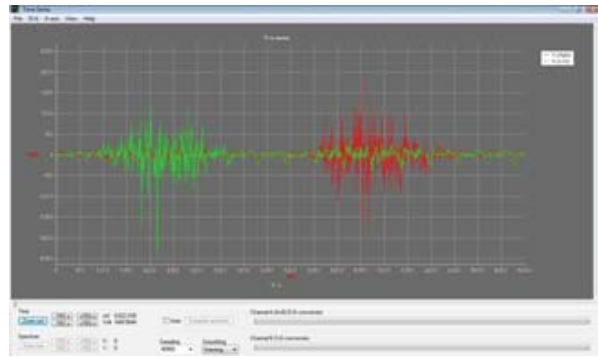
Fig. 2. The visualization of EMG signals using the Visual Analyzer software during voluntary contraction of symmetrical back muscles

nel, as well as synthesized sound accompaniment are provided. The synthesizer reacts to a change in the current signal's level by raising the sound's tone - if the signal's level is kept constant, there is no sound.

Channels of reception of an amplified EMG signal by a computer:

– computer's sound card;

– an external USB audio adapter that has all the necessary nodes to receive a signal, to convert it to a digital form and to transmit it to a computer using the USB protocol.

The EMG signal has a noisy character with a wide spectrum, and that's why it is difficult for visual analysis and requires special processing. The implementation of personal computers into the medical field enables to apply the automated mathematical processing methods and to store large amounts of information.

In addition to light indicators and a sound synthesizer, which are built directly into the functional and technological module, the amplified and processed EMG signals are transmitted to a computer, where the additional processing and transformation of information take place with a help of modern software tools. Since the frequency range of the EMG signal is included in the audio range for its analysis and processing the one of the available programs for processing of complex form signals in the audio range is used. The program that best meets the task is Visual Analyzer (Fig. 2).

With the usage of "MYOBALANCE" complex the previous study has been carried out to identify
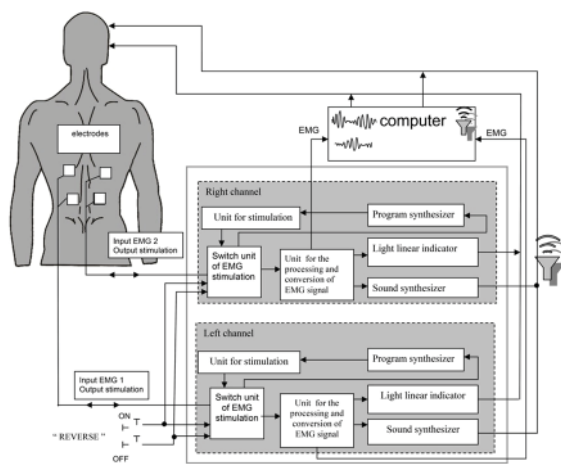
Fig. 3. Structural and functional model of the computer complex "MYOBALANCE-STIMUL" for personalized control of the balance and coordination of muscle activity

the muscles, on which the EMG signal can be an informative indicator for diagnostics of disorders of vertical orientation of the spine, as well as an indicator of the effectiveness of the disorders correction. As a result, the trapezius and broadest back muscles, the muscle that straightens the spine are chosen. The topology of the EMG signals is determined. The informativeness is due to the large size and superficial location of muscles, and the possibility of obtaining EMG signals with an amplitude that is sufficient for analysis [9].

Computer Complex for Diagnostics and Personalized Correction of Scoliosis Posture Disorders "MYOBALANCE-STIMUL"

Further research is aimed at developing the theoretical principles of synthesis and technical implementation of information technology for the correction of disorders of a vertical orientation of the spine and strengthening of a muscle corset. Depending on the diagnostics of a disorder, this technology performs personalized correction of scoliosis posture by using both the EMG feedback and the programmed myostimulation methods.

This technology is implemented by the "MYO-BALANCE-STIMUL" computer complex. The technical component of electrical stimulation is implemented by a two-channel programmed myostimulator "MyoBalanceStimul".

The structural and functional model of the synthesis of information technology for personalized correction of scoliosis posture is shown in Fig. 3. The two-channel programmed myostimulator "MyoBalanceStimul" is shown in Fig. 4.

The interaction of the technical component of the complex the two-channel programmed myostimulation device "MyoBalanceStimul" with a patient and a computer in the mode of diagnostics of the balance of activity of patient's back muscles, which form the vertical orientation of the spine, and the balance correction by the EMG feedback (visual and audio) method and programmed myostimulation.

The MyoBalanceStimul module amplifies, processes, transforms and transmits the EMG signal to a patient in the form of formalized light and sound signals, as well as transmits the EMG signal to a computer. EMG signals are registered from symmetrical back muscles with the help of skin electrodes, are transmitted to two channels inputs, are amplified, processed and transformed into light and sound signals, which, in turn, are a tool for visual and audio monitoring for static and dynamic work of symmetrical back muscles by using the EMG feedback method. In case of severe asymmetry of EMG signal levels, the patient voluntarily contracts the symmetrical muscles, visually monitors the level of voluntary movements, and strives to achieve the same level of EMG muscle activity with the help of visual and audio EMG feedback. The training of a patient is aimed at achieving the muscle balance and the fixing the correct motor stereotype. The correction of postural defects and the strengthening of muscle "corset" based on purposeful programmed electrical stimulation of the relevant muscles depending on the EMG signal indicators are achieved due to time separation of registration of the EMG signals from the symmetrical back muscles and electrical stimulation of these muscles. By default, the MyoBalanceStimul electronic module is in the state of registration of

the EMG signal and its analyzing visually both on the light linear indicators of device and with on a computer. The relation of the EMG signal levels according to the nature of a spine curvature can indirectly show nature of the pathology, which is an informative indicator for the relations of required levels of stimulation impact both in two channels and in required one.

Having received and recorded this information, with the "ON" button the electrodes are switched to a state of stimulation of the relevant signal level ("Reverse" state) from the program synthesizer. After the end of the specified stimulation time, with the "OFF" button the electrodes are switched to the state of EMG registration by pressing the "OFF" button and EMG analysis is carried out according to informative indicators on a computer.
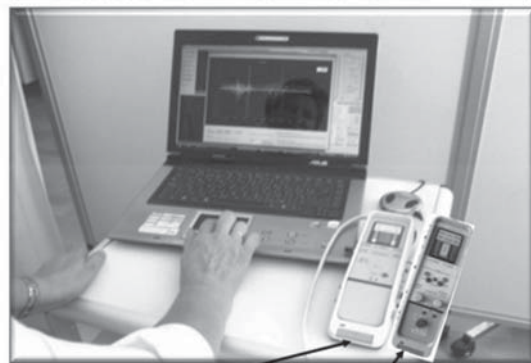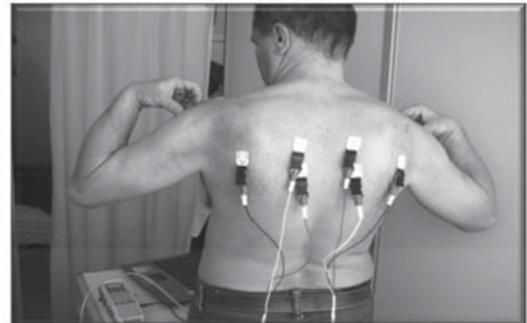
The two-channel electronic programmed myostimulation device "MyoBalanceStimul" provides the following functions:

— reception and amplification of EMG signals of muscles by two channels in the registration range of 20-1000 Hz in real time mode;

— light and sound control of the current EMG level;

— normalization of amplified analog EMG signals' level and their transmission to the linear inputs of a computer's sound card;

— transmission of the analog EMG signal from two channels to computer's USB port through an external USB audio adapter.

— mutual blocking of the EMG channels' outputs;

— on load equivalents the formation of the control impact on two channels by the amplitude-modulated pulse signals;

— amplitude modulation is carried out by both the average EMG signal's value and control impact signals of synthesizer;

— smooth adjustment of the output stimulating impact separately on each channel from 0 to 60 mA;

— switching in both channels of the registering electrodes to output stimulation effects on them.

With the usage of the "MYOBALANCE-STIMUL" complex, the diagnostics of scoliosis posture is implemented in the same way as it is with the usa-

Fig. 4 Two-channel programmed myostimulator "MyoBalanceStimul"

electronic functional and technological module "MyoBalance"   *two-channel programmed myostimulator "MyoBalanceStimul"*

Fig. 5. The diagnostics and correction of scoliosis posture based on the "MYOBALANCE-STIMUL" complex

ge of the "MYOBALANCE" complex — based on visual and audio EMG feedback method. However, the correction of scoliosis posture is carried out by both the visual and audio EMG feedback method and the programmed electromyostimulation method, which influences on the correction of the activity balance and muscle tone, the strengthening of the muscle corset, which affects the correction stability. This correction is implemented by a two-channel programmed myostimulator "MyoBalanceStimul" (Fig. 5)
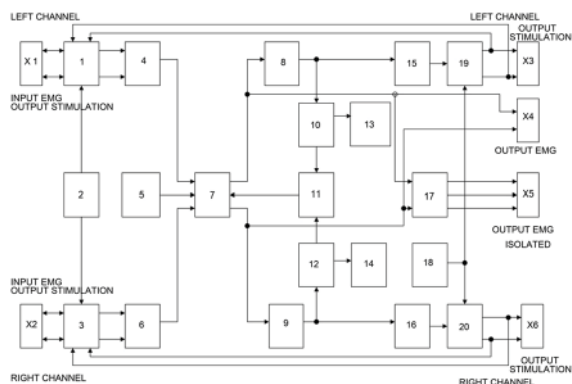
Fig. 6 . Structural and functional model of a two-channel programmed myostimulator "MyoBalanceStimul-2"

Fig. 7. Two-channel programmed myostimulator "MyoBalanceStimul-2". Device layout

To expand the functions of scoliosis posture correction by the programmed electromyostimulation method, to provide the choice of a personalized stimulation program depending on diagnostics of the balance's state, the set of electromyostimulation programs of two-channel programmed myostimulator "MyoBalanceStimul" has been expanded.

The upgraded version of a two-channel programmed myostimulator "MyoBalanceStimul-2" implements the following programs:

▪ "Donor". The registration and the stimulation electrodes are attached to the relevant muscles and connected to the relevant inputs and outputs. The contraction of recipient muscles occurs according to the law of changes in signals average value due to the contraction of the donors muscles independently in each channel.

▪ "Donor with mutual blocking". The algorithm is activated, according to which the priority appearance of the EMG signal in the left channel blocks the right channel for EMG signal registration and vice versa. Everything else is the same as in "Donor" mode. This program is used to control the antagonist muscles, when in the case of agonist contraction the antagonist must relax. It is implemented with the help of original technical solutions, when the priority appearance of the EMG signal in one of two channels blocks the other channel for registering the EMG signal and vice versa - a technical analogue of the braking reflex [10].

▪ "Synthesis". The stimulation occurs through the relevant outputs according to the law of the programmed synthesized sequence of control impacts. The repeating period of these impacts changes cyclically. In the "Synthesis" mode the "Reverse" state is implemented. With the activation of such state those donor muscles, from which the EMG was previously registered, are the subject for stimulation.

The module is equipped with a system of patient's functional protection against unauthorized applying a stimulating effect on the muscles in case of turning the power on and level regulators are not brought to "0" at the same time, and blocking the stimulating effect in case of unauthorized activation of the "Reverse" state.

Electronic module "MyoBalanceStimul-2" (Fig. 6) contains the following functional units:

$X1$, $X2$ − sockets for connecting the cables with three electrodes in the left ($X1$) and the right ($X2$) channels for the purpose of registering the EMG signals ("Donor" mode) and for transmitting the stimulation in "Synthesis" mode (state "Reverse" is on) to these electrodes;

*X*5 — the output socket of the current EMG from two channels, this socket is galvanically isolated from the electrical circuit of the device;

*X*4 — output socket of the current EMG from two channels;

1, 3 — toggle relays for switching the electrodes in the channels from the state of EMG registration from muscles to the stimulating these muscles;

2 — relay control unit with functional protection circuits. When the "ON" button is pressed, the relay switches the electrodes to stimulation ("Reverse" state). When the power is turned on, the relays are in the mode for the EMG registration;

4, 6 — amplifiers of EMG signals in the channels;

7 — switch of the device operation program:

1) "Donor": the registration of the EMG signal takes place through sockets *X*1, *X*2, and stimulation takes place through sockets *X*3, *X*6;

2) "Donor with mutual blocking" of registration channels: the registration of the EMG signal is blocked in that channel, where at the input of the *X*1 or *X*2 sockets, at the initial moment, the signal will be smaller or delayed in time; accordingly, stimulation occurs in another channel through the *X*3 or *X*6 socket;

3) "Synthesis": the stimulation occurs through sockets *X*3, *X*6 (the "Reverse" is off), or through sockets *X*1, *X*2 (the "Reverse" is on);

5 — synthesizer of sequences of control impacts of stimulation;

8, 9 — the integrators for extracting the average value of the current EMG in the channels;

10, 12 — voltage comparators for generating the blocking signals in "Donor with mutual blocking" mode;

11 — blocking device with an executive mechanism of the mutual blocking mode;

13, 14 — units for light and sound signaling of the current state level of the EMG in the channels;

15, 16 — amplitude modulators of the stimulating signal;

17 — unit for galvanic separation;

19, 20 — output amplifiers of the stimulating signal;

*X*3, *X*6 — sockets for connecting stimulating electrodes;

18 — generator of stimulating impact.

For informational assistance to the user and practical usability of a two-channel programmed myostimulator "MyoBalansStimul-2", a number of controlling, verifying, indicating and connecting controls are located on its panels (Fig. 7).

The "MYOBALANCE-STIMUL" computer complex enables to carry out the diagnostics and correction of scoliosis posture defects, which is aimed at developing a motor stereotype of symmetrical back muscles and strengthening a muscle corset, which are necessary to eliminate the spine curvature in the frontal plane, which contributes to the treatment of scoliosis posture. With the help of this complex, the user has the opportunity to verify the muscle activity of the symmetrical back muscles. This activity is an equivalent to the strength and the speed of muscle contractions, as well as muscle tone. The verification of the muscle activity helps to analyze the nature of its dynamics by the EMG feedback method and/or electrical stimulation by various programs. It is important that the *applied electrical stimulation is not separated from the motor act, which contributes to the development of muscle memory to produce the necessary motor stereotype*. Electrostimulation with various programs enables to carry out a dosed load, which prevents the fatigue of muscles are being trained.

The developed and technically implemented new science-intensive information technology for the correction of scoliosis posture disorders carries out the personalized correction of a muscle activity balance, muscle tone, the strengthening of a "muscle corset", that forms and maintains vertical orientation of the spine, depending on the disorders diagnostics. This technology is intended to preserve such an important function for human health as correct posture. And the increase in posture disorders in Ukraine is caused by the consequences of martial law, traumas and injuries both the military and civilian people, especially children.

Thus, the new information technology for correction of scoliosis posture disorders was developed and technically implemented. Depending on the diagnostics of disorders, this technology performs personalised correction of the muscle activity balance, muscle tone, strengthening of the "muscle

corset" that form and maintain vertical orientation of the spine. This technology is intended to preserve such an important function for human health as correct posture. In Ukraine, the increase in posture disorders is caused by the consequences of martial law, traumas and injuries both in military personnel and civilians, especially children.

Directions for Further Research

The main areas of further research are:

— testing for compliance with technical requirements and for usability of set of function, implemented by the "MYOBALANCE-STIMUL" computer complex and its components - two-channel programmed myostimulation devices "MyoBa-lanceStimul", "MyoBalanceStimul-2" and a computer.

— development of Instructions for practical usage of the "MYOBALANCE-STIMUL" complex and two-channel myostimulation devices "MyoBalanceStimul" and "MyoBalanceStimul-2", which will contribute to the expansion of their application not only in clinics, but also at home;

— transition to digital-analog technical implementation of two-channel myostimulators, which will contribute to the reduction of dimensions, energy consumption, increase in reliability, interference resistance, production of devices with modern interfaces, means for verification and diagnostics functionalities.

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ІНФОРМАЦІЙНА ТЕХНОЛОГІЯ ДІАГНОСТИКИ І КОРЕКЦІЇ ПОРУШЕНЬ СКОЛІОТИЧНОЇ ПОСТАВИ «МІОБАЛАНС-СТИМУЛ»

Вступ. Лікування й профілактика сколіотичної постави залишається актуальною проблемою сучасної ортопедії. Це пов'язано не тільки з поширеністю захворювання, особливо серед школярів, студентів та офісних працівників, що зумовлено зменшенням рухової активності, але й труднощами у своєчасній діагностиці та лікуванні.

Мета статті — розглянути теоретичні й практичні засади синтезу інформаційної технології діагностики і корекції сколіотичної постави, яку спрямовано на персоналізацію корекції м'язової активності, тонусу м'язів, зміцнення "м'язового корсета", що формують і утримують вертикальну орієнтацію хребта у фронтальній площині.

Методи: структурно-функціональне моделювання, ЕМГ зворотний зв'язок, програмна міостимуляція, методи оброблення і аналізу ЕМГ сигналів, програма *Visual Analyser*.

Результати. Розроблено теоретичні і практичні засади синтезу інформаційної технології діагностики і персоналізованої корекції сколіотичної постави на базі керування балансом активності м'язів, що формують вертикальну орієнтацію хребта залежно від стану балансу. Технологію реалізує комп'ютерний комплекс "МІОБАЛАНС-СТИМУЛ". До складу комплексу входять: 2-канальний програмний міостимулятор «Міо-БалансСтимул» або удосконалений, з роширеною гамою програм міостимуляції, 2-канальний міостимулятор «МіоБалансСтимул-2» та ПК. Застосування двох методів корекції — електроміографічного зворотного зв'язку і програмної містимуляції, відображення балансу активності симетричних м'язів спини на індикаторах стимуляторів і на ПК сприяють персоналізації, стійкості корекції, оцінюванню її ефективності, зміцненню "м'язового корсета", запобіганню розвитку ускладнень.

Висновки. Подальші дослідження спрямовано на зменшення габаритів і зручність використання комплексу не тільки у клінічних, але й у домашніх, польових умовах лікування сколіотичної постави, що зумовлено поширеністю захворювання в Україні внаслідок травм і поранень військових, цивільного населення, особливо дітей.

Ключові слова: сколіотична постава, діагностика, персоналізована корекція, електроміографічний зворотний зв'язок, програмна міостимуляція, комп'ютерний комплекс.