# ORIGINAL ARTICLES

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## The concept of postural pattern formation in patients with posttraumatic diaphyseal deformities of the long bones of lower extremities

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*Objective. To invent the concept of new postural pattern formation in the consequence of severe injury of lower extremities associated with the development of «syndrome of posttraumatic diaphyseal deformities of lower extremities». Methods. The classic model of the development of transformation «health–disease», that was initially worked out in 1960th years, has been used to build up a concept of the returning of patient from trauma to relative health. The idea of this approach was to make analogy of regulatory process under the conditions of disease with emergency control in sophisticated technical systems of automatic control. The results of instrumental investigation of patients and mathematic modelling was used. Results. In the case of the development of «syndrome of posttraumatic diaphyseal deformities of lower extremities» in addition to decreased muscular strength, joints stiffness and limb lengthening the complex of following complications occurs: anatomical disarrangements in adjusted joints and muscular imbalance. If the deformity development is accompanied by the saved weightbearing function of the limb a compensatory mechanism in length of time and in a process of walking capacity restitution creates new «body scheme» and stereotypes of walking and standing. Inherent program of movement substitutes with acquired one. If the deformity occurs just on one lower extremity the anatomical disarrangements of the whole skeletal system take place: the tilt of pelvis and spine, hip abduction/adduction contracture, varus/valgus deformity in knee joint, the disturbance of weightbearing capacity of feet with different derangements in ankle and subtalar joints (including varus/valgus deformities). The severity of these secondary changes depends upon the value of deformity, general and psychological status of patient. Outcomes. Invented concept of new postural pattern formation in consequence of severe injury of lower extremities associated with the development of «syndrome of posttraumatic diaphyseal deformities of lower extremities» allows to assess and understand a locomotor behavior of patient and take it into consideration in treatment planning. Key words. Postural pattern, posttraumatic deformity, lower extremity, secondary changes, adaptive changes.*

*Мета. Створення концепції формування нового постурального патерну внаслідок перенесеної важкої травми нижніх кінцівок із розвитком синдрому діафізарних післятравматичних деформацій довгих кісток нижніх кінцівок. Методи. Для побудови концепції повернення хворого від травми до відносного здоров'я розглянуто модель класичного розвитку «здоров'я – хвороба», розроблену в 1960-х роках. Ідея підходу полягала в проведенні аналогій між процесом регулювання за умов хвороби й аварійним регулюванням у складних технічних системах автоматичного управління. Використано результати інструментальних обстежень пацієнтів і математичного моделювання. Результати. У разі розвитку синдрому діафізарних післятравматичних деформацій довгих кісток нижніх кінцівок, крім зменшення сили м'язів, розвитку контрактур і вкорочення кінцівки, формується низка ускладнень: одночасно з деформацією кістки виникає порушення анатомічних співвідношень у суглобах і стійкий м'язовий дисбаланс. Якщо за наявності деформації зберігається опороспроможність кінцівки, через деякий час у процесі відновлення можливості ходити компенсаторні механізми створюють нову «схему тіла», стереотип стояння та ходьби. Уроджена програма руху змінюється на набуту. За деформації однієї кінцівки порушуються анатомічні співвідношення у всьому скелеті: формується нахил таза і хребта, у кульшових суглобах виникають привідно-відвідні зміни, а з часом контрактури, у колінних — варус/вальгусні деформації, змінюється опороспроможність стоп із формуванням також варус/вальгусних деформацій у надп'ятково-гомілкових і піднадп'яткових суглобах. Важкість змін залежить від величини деформації, загального та психологічного стану пацієнта, його настрою. Висновки. Створена концепція формування нового постурального патерну внаслідок перенесеної важкої травми нижніх кінцівок із розвитком синдрому діафізарних післятравматичних деформацій довгих кісток нижніх кінцівок дає змогу зрозуміти рухову поведінку пацієнта й враховувати її під час визначення тактики лікування.*

**Key words.** Postural pattern, posttraumatic deformity, lower extremity, secondary changes, adaptive changes

## Introduction

The issue of defining health and disease has been considered by doctors and physiologists for many centuries. There are many definitions of these states of the human body, and in the meaning of «health» there are semantic contradictions: for some authors «health» is a state, for others a property, ability, category, whereas according to some scientists the concept of «health» is rather a philosophical generalization [1]. This led the researchers to conclude that the main difficulty of the evidentiary formulation is associated with «weak implementation of the system-cybernetic approach in integrative medicine» [2], i. e. in the multidisciplinary direction of studying the physiological foundations of «health / disease».

There are several systems of transition from «health» to «disease». But the mechanisms of returning the system from the state of «disease» to the state of relative «health» are practically not considered. This problem is explained by the fact that the return of the human body from the state of «disease» to the state of «health» occurs not only through the restoration of its homeokinesis [3], but also through adaptation, which is not always a positive factor [4].

Trauma (in our review we consider fractures of the bones of the lower extremity) is a physical stressor that immediately transfers the body from a state of «health» to a state of «disease». Severe trauma associated with a prolonged recovery process is complicated by a number of aggravating factors, such as prolonged immobilization, hypodynamia, reduced muscle strength and the development of contractures, concomitant dysfunction of internal organs and systems. That is, full functioning of the body requires not only healing of the fracture, but also restoration of impaired functions. Recovery process is often complicated by consolidation of fragments with unremoved displacement, or formation of non-unions and defective joints, including persistent deformations. This results in the development of a complex of secondary changes in the damaged segment [5] and, sometimes, in both lower extremities and girdle of the lower extremities, which should be combined, considering them as a syndrome of diaphyseal post-traumatic deformities of long bones of the lower extremities. These pathological conditions require the formation of new skills of standing and moving and, over time, a new postural pattern of the body.

*The purpose* of the study was to create a concept of formation of a new postural pattern due to severe trauma of the lower extremities with the development of syndrome of diaphyseal post-traumatic deformities of the long bones of the lower extremities.

## Material and methods

The study involved assessment of literature sources of models of transition from «health» to «disease». A model of the classical development of changes from «health» to «disease» was considered to build the concept of returning the patient from injury to relative health.

In physiology, there are several patterns of transition from «health» to «disease». The first theoretical models of this transition were developed in the 1960s [6, 7]. The idea of the approach was to draw analogies between the process of regulation in disease and emergency regulation in complex technical systems of automatic control. Modeling showed that one of the main differences between the process of regulation in a disease from physiological regulation is the same thing that distinguishes emergency regulation in technical systems from normal, namely a change of purpose. If in physiological regulation each biological system has its own purpose, arising in the process of evolutionary development [8], for instance, moving in the direction of optimal conditions or performing any specific function, then in the case of regulation there is a new one: self-preservation of the system in the near future.

Graphically, the situation can be represented as N-dimensional space (for simplicity, presented as two-dimensional). On axes of the ordinates the boundaries of the norm are conditionally marked (*a*), the boundaries of compatibility with life (*b*). Within *a*, there are values of all parameters optimal for the main task of the system (in our case, maintenance of postural balance), it is a zone of physiological control, «health». Zone *B* is emergency regulation (Fig. 1).

If due to pathogenic influences any parameter goes beyond *a*, then there is a danger of its going beyond *b*. Prevention of this situation is achieved when a number of parameters actively go beyond *a*, because without this self-preservation of the system in the near future becomes impossible. As a result, most of the regulated parameters fall into zone *B* (emergency regulation), i.e. into the zone of «disease». The system gets destroyed if the line of boundary *b* is reached.

At the beginning of the disease, the task of returning physiological parameters to zone *A* due to the functioning of regulatory mechanisms of recovery may be in the background, but over time, the task of normalization plays an increasing role. Favorable course of the transition process results in recovery or compensation of partially lost opportunities.

Later, a more detailed scheme of transition from «health» to «disease» and then to the destruction of the system was proposed [10] (Fig. 2). This model considers the boundary a in more detail (Fig. 1).

According to Glenn and Avicenna, transition periods are not «health» or «disease», but the functional state of the body between norm and disorder. The transition from «health» to «disease» is associated with a decrease in the body's adaptive capacity, ability to respond adequately to stress and excitatory mechanisms. We will not go into detail about what happens in each period of transition from «health» to «disease» because we are interested in the return path from «disease» (in our model, a serious injury) to «health» (stabilization of postural function).

In our conceptual model, we will consider the development of the disease only in view of orthopedic disorders, without taking into account the concomitant disorders that can be observed in severe injuries or in past history.

The concept of forming a new postural reality in patients with the syndrome of diaphyseal posttraumatic deformities of the long bones of the lower extremities will not be complete without disclosing the concept of forming a «body diagram» and normal postural function.

The control of vertical posture, carried out by a person throughout life, is an important physiological function of the body. There are two types of motor functions: support of vertical position (posture) and the actual movement, it is impossible to separate them from each other. The central place in the regulation of posture is occupied by the «scheme of the body», the generalized sensitivity of one's own body at rest and during movement, location and change of spatial coordinates and relationships of body parts. The physiology of the organization of the human motor system [12] and the formation of its own «body scheme» [13] are perfectly disclosed in textbooks and reference books on human physiology. Researchers of the Laboratory of Biomechanics of the State Institution «Professor M. I. Sytenko Institute of Abnormalities of the Spine and Joints of the National Academy of Medical Sciences of Ukraine» created and tested a conceptual model of changes in the congenital postural pattern («body scheme») under the influence of a long degenerative process [14].

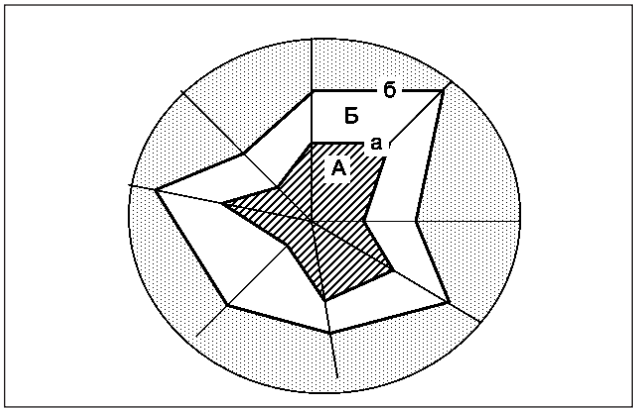


**Fig. 1.** Limits of norm (a) and limits of compatibility with life (b) in the N-dimensional space of signs: *A* — zone of physiological regulation («health»); *B* — emergency control zone («disease») [9]

## Results and their discussion

Let us dwell on the basic provisions of the physiology of the «scheme of the body» formation. Integrative processes of its formation are completed in the adult organism, it fixes the schemes of mutual arrangement of body parts during automated stereotyped movements (standing, walking, actions performed at subconscious level). Personal pattern of movement (including standing as one of the types of movement) is created under the influence of its own receptors (vision, hearing, tactile, vestibular, etc.) (Fig. 3).

The optimal position of the body in space is a closed control system, comprising the central nervous system that contains elements responsible for maintaining genetic and acquired movement programs, ways to correct these programs depending on external influences and the state of the body.

The system of postural regulation is a set of reflex inverse connections from the signals of the vestibu-

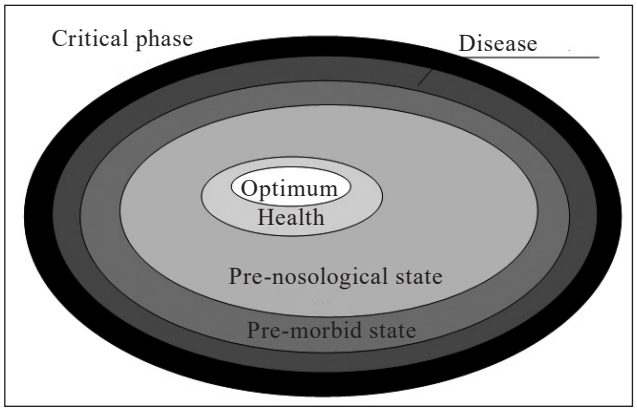


**Fig. 2.** Transition periods from «health» to «disease» optimum [10]

lar apparatus, visual and auditory systems, joint and muscle receptors. The interconnection of the body's systems is carried out in accordance with the conditions in which the task of maintaining posture or movement is solved, so that in a situation where one of the sources of information does not give the correct signal, its function is compensated by others. This causes the body's adaptive reactions. Based on the conceptual model of the change of the congenital postural pattern («body diagrams») [14], we developed a system of postural regulation of movement (normal) to study the change of congenital motor patterns after injuries (Fig. 4).

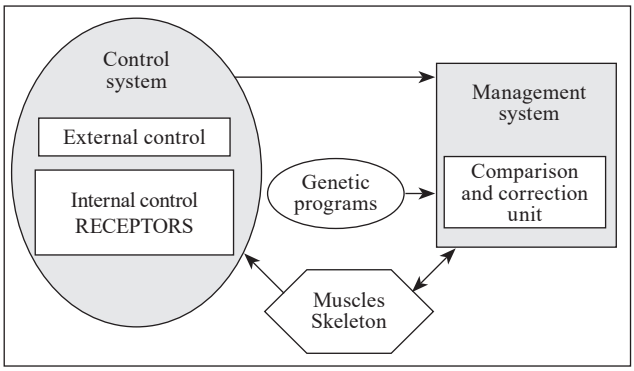


**Fig. 3.** The mechanism of movement organization [12]

Let us return to the mechanism of the transition «health-disease». In degenerative diseases, or diseases that develop over a long period of time, a person forms a new «body scheme» through the involvement of adaptive mechanisms with the subsequent change of genetic postural programs. The course of degenerative diseases is accompanied by periods of remission due to therapeutic treatment or exacerbation. After radical treatment, such as arthroplasty, the patient's condition improves, gradually returning to the point of adaptation (relative health). After the injury, a new «body pattern» is formed during recovery.

Thus, under conditions of injury, the patient immediately falls into the zone of «disease» bypassing periods of adaptation and compensation, i.e. forming a new «body scheme», but a new «movement strategy» and a program of its regulation are absent. They will be formed in the process of recovery.

In the case of mild and moderate injuries, which heal relatively quickly, with adequate treatment and proper rehabilitation, a person is able to return to the zone of «health», i.e. to fully restore functionality (Fig. 5). This is facilitated by adequate fixation of bone fragments after fracture, which allows the earliest possible functional load of the damaged segment.

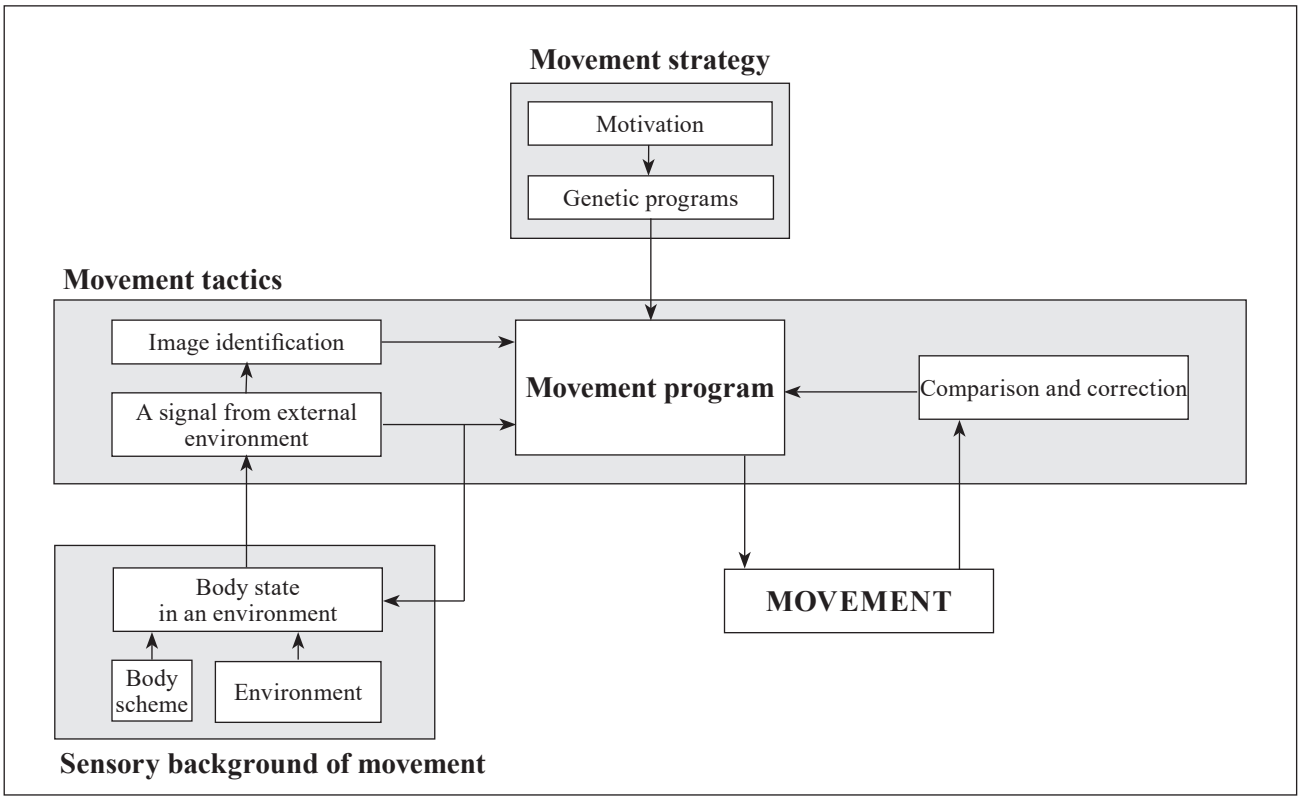


**Fig. 4.** System of postural regulation of movement (norm)

Under opposite conditions (inadequate fixation of fragments and lack of appropriate rehabilitation and early functional load), in the development of diaphyseal post-traumatic deformity syndrome of long bones of the lower extremities, patients are forced to form a new «body scheme» and, accordingly, develop a new control system.

Treatment of diaphyseal fractures of long bones is accompanied by a certain period of immobilization and restriction of mobility and resistance of the injured limb. This reduces muscle strength by 10 to 20 % per week for various groups and types of mobility impairment [15]. Restriction of movements in the joints results in formation of immobilization contractures.

In normal fracture healing and adequate rehabilitation over a period of time, limb function and muscle strength are restored to physiological norm.

In the case of the syndrome of diaphyseal post-traumatic deformities of the long bones of the lower extremities, in addition to decreased muscle strength, contractures and shortening of the limb, a number of complications occur: simultaneously with the deformation of the bone, the anatomical relations in the joints are disturbed and a stable muscle imbalance is created. If in the presence of deformity, the limb preserves its leaning ability, after some time in the process of restoring the patient's capability to walk compensatory mechanisms create a new «body pattern», forming a new stereotype of standing and walking and the movement program changes from congenital to acquired. In injury of one limb, complicated by deformation with all severe consequences, the anatomical proportions change in the joints of the entire skeleton: formation of tilted pelvis and, accordingly, spine; adduction-abduction disorders in the hip joints, and over time, contractures; varus/valgus deformations in the knee joints due to different heights of their flexion and violation of spatial orientation; leaning ability of the feet changes with further formation of varus/valgus deformities in the tibial and subtalar joints. The nature of the changes certainly depends on the magnitude of the deformity and its direction, as well as the general health of the patient. A significant role is played by patient's perception of the new state of the body, i. e. from psychological state and mood.

The conceptual model is based on indicators of instrumental examinations of patients (radiological, statographic [16]), as well as the results of modeling (finite elements of the stress-strain state [17] in the joints and dynamic modeling of walking to determine changes in muscle function [18] by conditions of deformation of long bones of the lower extremities).

Let us consider the scheme of development of adaptive changes in the musculoskeletal system of the patient in the case of post-traumatic deformities of the long bones of the lower extremities.

Any severe injury, especially in the absence of adequate treatment (proper stabilization of fragments and rehabilitation), is accompanied by a relatively long period of immobilization or significant limitation of limb mobility. This causes loss of muscle strength and the development of immobilizing

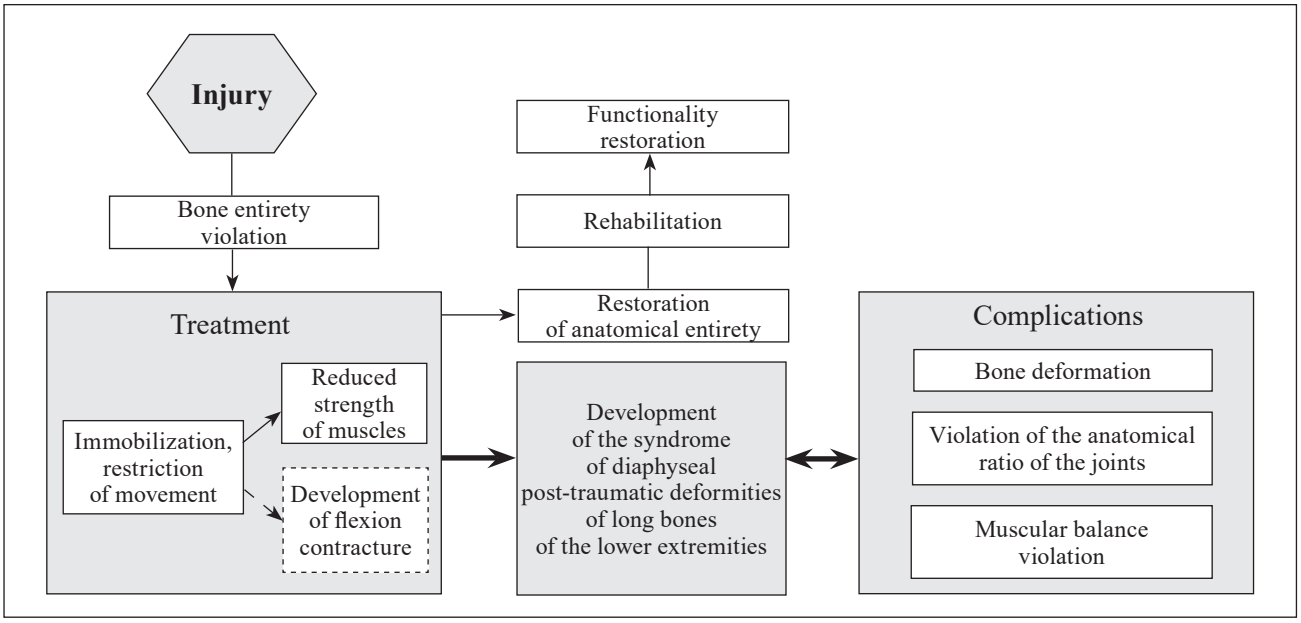


**Fig. 5.** Possible mechanisms of consequences of injury treatment

contractures. During the formation of post-traumatic deformation of long bones, there is usually a shortening (different types) of the limb, which increases with the expansion of the deformation angle.

Changing the anatomical position of the bones of the limb leads to a shift in the anatomical orientation of the articular surfaces, and, accordingly, modification of the load in the joints. This constitutes a risk of developing dystrophic disorders.

It should be noted that varus deformity of the middle part of the femur or tibia causes valgus installation of the knee and ankle joints with an overload of the medial parts of the joints. In the hip joint, the femur moves to the position of abduction, the range of which also depends on the range of the angle of deformation. In severe varus deformities, the contralateral limb focuses on adduction.

Valgus deformity of the long bones leads to compensatory abduction of the femur to maintain the axial balance of the limb, the knee and ankle joints go to the varus position with overload of the lateral structures. Relevant changes also affect the ankle joint [17].

Accordingly, with a change in the orientation of the bones, the direction of action of muscle forces changes, and on the convex side of the deformity the muscles are constantly stretched, and on the concave side, on the contrary, are in a contractile state, which in both cases interferes with comprehensive muscular function.

It should be pointed out that at significant angles of deformation (according to modeling results, over 30°) the knee and ankle joints are not able to fully restore the axial stability of the limb, so we observe dysfunction of the leg and foot muscles responsible for stability. This is due to the fact that in the compensation of the axis of the limb a significant role belongs to the ankle joint, which has more degrees of latitude, the knee joint is much less involved in this process due to only two degrees of latitude, and varus/valgus changes occur slowly in long course of the disease.

In shortening of the deformed limb by more than 2 cm (anatomical norm of the difference in the length of the limbs) compensatory flexions are formed in the hip and knee joints on the contralateral one. They bend at different levels and in different directions. Limb shortening causes pelvic tilt with all the associated problems [18].

Altered orientation of bone and joint structures, impaired muscle balance and shortening of the limb lead to impaired standing and walking, lameness. Prolonged inadequacy of the load zones causes the development of dystrophic changes. At patients with prolonged changed «scheme of a body» were found to form a corresponding compensatory program of movement (Fig. 6).

Constant correction of motor behavior modifies the genetic motor program to the acquired pathological one. It is known that the compensatory mechanisms of the body are quite developed. A person is

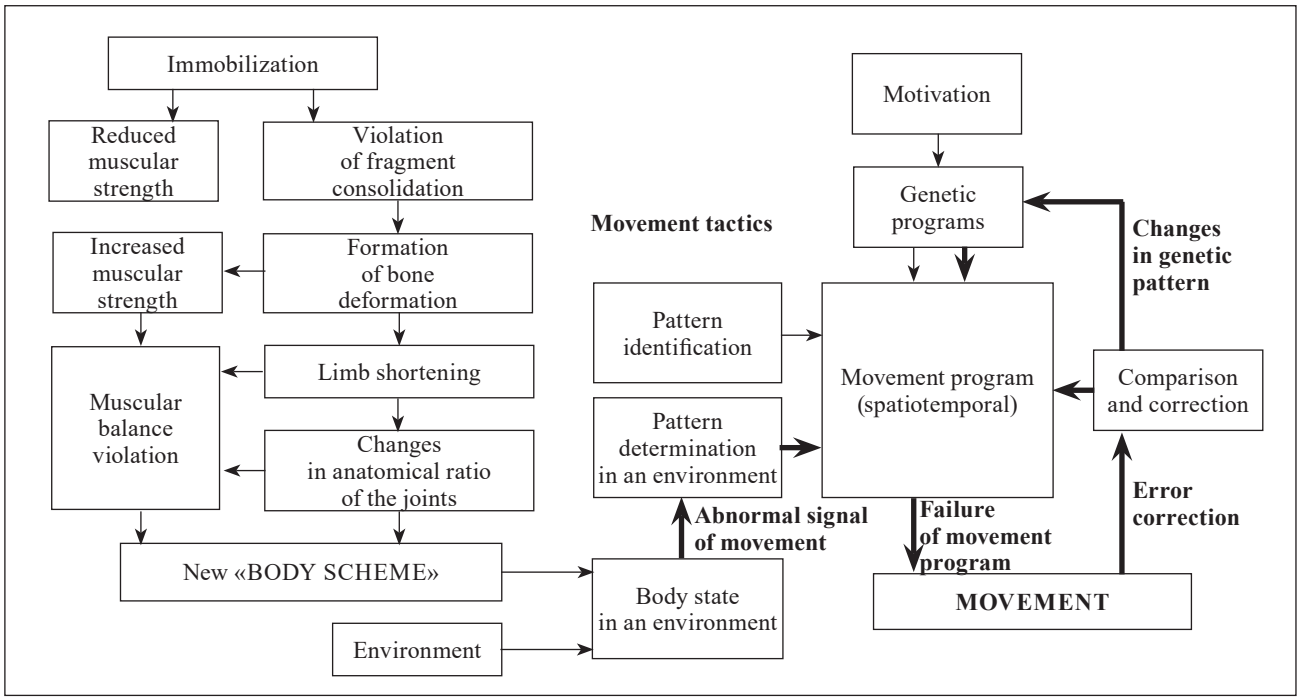


**Fig. 6.** Model of formation of a new «body scheme» and program of movement

able to restore motor activity using additional backup sources. For example, shortening of the limb is proportionally compensated by changing the angles of the pelvis, flexion / extension / adduction / abduction of the joints. A decrease in the strength of one muscle group is compensated by an increase in the strength of another. But the biggest changes occur in the motor program. During standing, the load on the injured limb decreases, towards which, due to the need to maintain the axis of balance, the torso tilts. The body weight is shifted towards the contralateral limb. During walking, its pattern completely changes, the step length of the injured limb decreases, due to the change of its abduction, there is an asymmetry of the base of the steps and the angle of feet position. Dysfunction of the joints results in an asymmetry of goniometric parameters.

Thus, after the formation of an adaptive motor pattern, some patients can live a full life, albeit with limited motor function. That is, if we return to the concept of «health», then after a while the patient falls into the zone of adaptation.

The question of whether these patients can be considered «healthy» is rather in the context of an individual approach, taking into account the requirements of the patient. Doctors usually consider a person with disabilities to be unwell, but the patient considers himself healthy. In recent years, a new paradigm has been formed in assessing the health of people with disabilities: people with unprogressive disabilities who have adapted to their condition are considered healthy, but with regular prevention and early recognition of «secondary conditions», including injuries and lesions (pain, contractures, osteoporosis, etc.), progression of the disorder and age-related deterioration of functions [19].

## Conclusions

The concept of forming a new postural pattern due to severe trauma of the lower extremities with the development of diaphyseal post-traumatic deformities of the long bones of the lower extremities allows to analyze and understand the motor behavior of the patient and take it into account when determining treatment tactics.

**Conflict of interest.** The authors declare the absence of conflict of interest.

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# THE CONCEPT OF POSTURAL PATTERN FORMATION IN PATIENTS WITH POSTTRAUMATIC DIAPHYSEAL DEFORMITIES OF THE LONG BONES OF LOWER EXTREMITIES

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