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Biomechanics as an Element of the Motion Clinimetry System

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Abstract

The study highlights the great progress in medicine, currently capable of a criterial, qualitative diagnosis of an increasing number of primary and secondary diseases in the musculoskeletal system, regardless persistent obstacles to a credible, systemic, and quantitative evaluation of the extent of existing motion dysfunctions, as well as subjective dimension of patient's suffering. It is worth to add that only parametric estimation of a qualitative dysfunction profile makes it possible to reliably monitor treatment efficiency and forecast the level of health damage after its termination. The essence of biomechanics, understood as a science describing internal and external forces' vectors, which determine specific, dynamic motion models (especially for balance and gait), has been presented in the study. Special attention has been given to anthropomotorics and psychomotorics, which give a broader context to motion's driving phenomena and consequences, thus offering a variety of new parameters that have not been considered in close relation to motion so far. While developing symmetry concept, it was pointed out that dysfunction profile comprises of sequences of parametric asymmetries registered in twin body markers.

Keywords: essence of biomechanics, anthropomotorics, psychomotorics, concept symmetry of body parameters, clinimetry, registers static and movement parameters

1. The essence of biomechanics

Biomechanics is an element of clinimetry, which registers movement parameters and analyzes complex inter-parameter phenomena, mainly to an extent to which they reflect the impact of internal and external mechanical forces. There are two main directions in observation, namely, retaining balance and moving body (or its parts) within Earth's gravitational field. In biomechanics, there is a slightly archaic and misleading but still bounding division for statics (applicable exclusively to the rigid bodies) and dynamics, which seems to overlook the fact that maintaining a seemingly static posture results from a conjunction of micromovements that project the center of gravity into a closed curve of critical supporting plane. A distinguishing criterion between a seemingly static and dynamic behavior of a living organism lies exclusively in technical capability to register micromovements as well as macroscopically visible movements [1]. In classic approach, dynamics can be divided into kinematics, describing movement geometry, and kinetics, describing movement's driving forces. In the state of static balance, as well as in any body's movement, the impact of certain forces can be evidenced, relying on well-known physical principles, especially vector geometry [2]. However, is the location of the center of gravity

and inertia, balance, and vector calculus of marker points of the human body equal and repeatable as in the case of the description of the twin points of a rigid body, e.g., a stone sculpture or a polyester 3D print of a human body? Are there in practice differences between the physical characteristics of the behavior of marker points of rigid bodies and living organisms composed of multi-compartment, complex rigid systems with a specified number of degrees of freedom (bones and joints) and viscoelastic kinetic-buffering systems, with stiffness varying depending on the concentration and the direction of ion migration and the current pattern of reflex muscle tone stimulated by the extrapyramidal system? Is the repeatability of the vector calculus (for two bodies of identical mass) carried out after the action of force with constant parameters different for the marker point, which is part of the homogeneous structure of the rigid body, compared to the description of the marker of a multi-compartment rigid-viscoelastic system? What is the parametric drift of the viscoelastic system, the rigidity of which is interactively modified by a vector of information flowing from the inside of the body and the environment through receptors to the CNS and then by extrapyramidal pathways of the spinal cord to the muscles?

Biomechanics seeks to answer many of these questions pragmatically, by means of creating parametric sets for functions of motion markers in healthy individuals in various age groups, e.g., in the development period (evolution patterns) and in the old-age period (involution patterns) [3]. Clinical biomechanics covers sets of parametric differences in motion dysfunctions caused by a number of disease processes [4]. When applying mathematical formulas for describing rigid bodies in clinical biomechanics, it should be noted that motion is an effect of not only external and internal forces but also other internal factors, such as information vector, which is not usually directly associated with the causative aspect of motion, or else there is no relevant mathematical formula to describe it yet [5]. An important element of basic research on human motility is modeling, where body movement is treated as an effect of a control process, in which the controlled object is a simplified, mechanical model of a rigid-viscoelastic anatomical structure, and the controlling element is a regulator, which reflects the functions of sensorimotor part of the nervous system. Built in this way, a motion model is subjected to the computer simulation and later to a correlation analysis with real data acquired from sensors installed on volunteer's body, in order to modify the model. Therefore, when planning to improve biomechanical models, it is worth thinking about adding other factors to the vector analysis that may play a role in increasing the reliability and repeatability of the description of the movement of biological organisms [6]. So far, none of the existing research patterns were able to meet the strict consistency criteria in science. Every theory requires to be confirmed by experiment, and attractive, probabilistic models, which were constructed so far, operate in isolation from the actual empirical data and have moderate practical significance [7, 8].

Distinguishing anthropomotorics as a science was an attempt to find a compromise between the inductive and deductive approach in studies on human movement—it seeks to objectively examine the phenomenon of motility in all its aspects in order to provide the specialists in various fields with one uniform pattern, which would correspond with results of the real measurements. One of the most important issues in the field of anthropomotorics is an attempt to cybernetically define the characteristics of the control system (regulator) included in the model above—its functioning defines complex paths of interactions between sensors and motion effectors (muscles) and moving rigid modules (bones), connected by ties (joints) with a certain number of degrees of freedom [9–11]. Research on the complex functions of the motion regulator funded a new discipline—psychomotorics—which defines the role of senses, largely proprioceptive (tensometric strain

gauges) and labyrinth (accelerometer-gyroscope) sensors, and the use of information obtained through them to modulate the course of movement in terms of purpose function (verified by the telereceptors) [12–14]. It is worth to remember that psychopathological phenomena, and even transient emotional states that modify one's personality profile, influence the motion control, causing visible amplitude-interval changes, e.g., in Californian motion determinants. This is why it seems very legitimate for various authors to suggest the necessity of testing the stability of this biological regulator also in psychological aspect, by means of parallel use of psychometrical test and movement metrology [15–17].

2. Structural and functional symmetry of the body

Majority of living organisms that have evolved in the gravitational field of the Earth, except for a large part of protozoa, known as non-axial, developed at least one symmetry axis and usually a symmetrical arrangement of many internal organs and body parts. The symmetry of the body is, therefore, a basic and quite specific feature of the structure, defining the distribution of its parts in relation to the adopted axis or plane. Using the symmetry criterion, the organisms can be divided into:

1. Radial symmetry organisms having a large number of symmetry planes, running through the body along a single symmetry axis. According to the number of rays, they can have either a biradial symmetry (for two radii and two planes of symmetry) or a quadriradial symmetry (the four radii and four planes of symmetry). Examples include vascular plants, sponges, polyps, jellyfish, coelenterata, polychaetes, and echinoderms [18].
2. Organisms with bilateral symmetry, defined by the plane running along the main (long) body axis, which divides it into two parts, the right and the left. Bilateral symmetry is a construction plan both for animal (e.g., amphibians, reptiles, birds, mammals) and plant organisms (uni- and multicellular) [19].

Each of the organ pairs existing in the living organism (with bilateral symmetry), despite the high level of structural distinctiveness, functions in a substrate-coupled manner with odd central organs (heart, liver) by means of mirror elements of the vascular system and information coupling with the brain via the peripheral nervous system, seeking to maintain their structural and functional symmetry. It has been proved that information and ion-molecular regulatory phenomena that penetrate from the microscopic to macroscopic scale, by maintaining functional symmetry, also tend to maintain structural symmetry that can be found in shape geometry at all levels of twin organs (e.g., limbs). These features can be described by the laws of formal logic and reflected in a model as structural-functional symmetries of parameters, not only amplitude-angle but also thermo-emissive, rheological, magnetometric, resistive, and electrometric. As mentioned above, one example can be balance in a seemingly static standing posture, which is a characteristic feature of human motor activity, defined as the body's ability to maintain body position without assistance, allowing to maintain this state during and after specific activities [20]. Balance in its essence is therefore a dynamic act of mobility, whose stability is conditioned by the efficiency of spatial neuromuscular coordination in the field of statokinetic microreflexes. Its expected result is the projection of the body's gravity center into a closed critical curve of the supporting plane, thus maintaining the standing posture. This feature is one of the external manifestations of

the homeostasis of the body, which tends to keep symmetry of function in the twin body organs. Thus, both the statokinetic micromovements that condition maintaining a relaxed standing posture and more easily discernible features of the symmetry of gait phases indicate the efficiency of the osteoarticular, muscular, and nervous systems. Another variable characteristic of balance is stability, that is, the ability to restore the position of the body in space, that was lost as a result of external forces or one's own physical activity.

3. Anatomical and functional outline of balance phenomena

There are three main groups of receptors adapted to the perception of the data necessary for the smooth functioning of the regulator in control of body balance (seen as an irregular body), namely, the vestibular system, the proprioceptor system, and eyesight and hearing under certain conditions. *Signals generated by these structures are a source of information about the position of the body and its orientation relative to external and internal reference systems* [21].

In the process of postural balance control, human brain creates an internal reference system in the form of a symmetric, proprioceptive simulation, which is a dynamic, spatially symmetric strain gauge load distribution model in the body's schemes of postural and motor habits, calibrated by an external reference system and engrams of acquired variants of gravity deviations [22]. This model is referred to as an external visual reference system, which is a dynamic, optical model of the external space, which surrounds the subject [23–25]. Under specific conditions, acoustic model can also be considered [26]. One of the elements of the subject's interaction with an external reference system is the need to determine the relationship of its own dimensions in relation to the marked, repetitive components of the environment. Archaic measurement systems (where, e.g., foot and cubit serve as a unit) were created in this mechanism. Internal and external markers allow to monitor the deviations of the center of gravity and inertia of the body and even its individual parts from the state of balance. Anatomy-wise, eyesight and the vestibular system are organs that monitor the position of the head in space, whereas proprioceptors and exteroceptors form a network of sensors covering the whole body. Each of these recorders collects a different type of data that individually affects the operation of the regulator and systemic balance control in a specific way [27].

In this context, it is worth to mention the structure of the vestibular system, which is composed of three semicircular canals located in mutually perpendicular planes. On the inner walls of the channels, there are receptors (hair cells) transmitting information on the direction and speed of movement of the head. Other parts of the vestibular system, saccule and utricle, are located at the base of the semicircular canals. From a structural point of view, they are two chambers filled with endolymph, in which the bottom walls have concentrations of hair cells—their cilia are located between the otoliths submerged in endolymph, which are built of crystals of calcium salt crystals. Their function is similar to the seismic mass in accelerometers. Signals from these organs transmit information about the static position of the head in space, first to the spinal cord via the vestibular nuclei. This is followed by the integration of signals from the otoliths, cerebellum, and spinal cord in the lateral vestibular nuclei (Deiter's nuclei), where efferent signal sequences that stimulate α - and β -motor neurons of the spinal cord (in control of muscles) are being generated [28].

As already mentioned, the regulation of spatial orientation, of balance in particular, is also based on the analysis of the image registered by the eye. In this case, the role of the external reference system is performed by the geometrical relations

of the spatial location of other objects on the proximal and distal set. In the neural network of the retina, there are specialized groups of neurons that perform loss conversion of the image fragments in order to obtain the vertical and horizontal gradients. These data have a similar role to the signals from the vestibular system [29–34].

The network of proprioception receptors (proprioceptors) is located mainly in collagen bonds connecting rigid modules (bones), i.e., in joint capsules, ligaments, and tendons, as well as in viscoelastic modules (muscles). A network of sensors sensitive to mechanical deformation generates data to create a projection-proprioceptive simulation, and after the confrontation with the model's pattern database—a proprioceptive-cognitive simulation of spatial distribution of the load in the individual body modules, the rigidity of viscoelastic elements and intermodular stress. The conversion and transmission of this data to the dimension of conscious feeling give practical information about the mutual orientation and movement speed of the body modules [35–38].

Type I mechanoreceptors are usually composed of 3–8 recording structures (40–100 μm in size) and are usually located in the outer (fibrous) layer of the joint capsule. Their characteristic feature is low excitability threshold, enabling the generation of positional information about the angular position in the joint.

Type II mechanoreceptors are usually built of 1–2 recording structures (100–280 μm in size), located in the inner layer of the joint capsule. Their characteristic feature is low excitability threshold, as well as generating information about the direction of motion.

Type III mechanoreceptors are composed of 1–2 registering structures (100–600 μm in size) with high excitability threshold. Being located in enthesis, they generate alarm information about muscle and tendon overtension.

Cutaneous mechanoreceptors respond directly to the movement (as a change in shape) or indirectly, through skin contact with clothing and other objects. Type I cutaneous mechanoreceptors, known as the Meissner bodies (detectors of motion speed) and Merkel bodies, are most commonly located on the palms, feet, and lips. They are characterized by a lack of spontaneous activity and high sensitivity to skin movements, allowing for surface type and shape cognition. Type II cutaneous mechanoreceptors, known as Ruffini and Pacini bodies, are most often located on palms, feet, and trunk. They display spontaneous activity for skin deformations and stretching resulting from mechanical stimuli in areas distant from the receptor. In their action, they have a static component, dependent on the strength of the stimulus, and a dynamic component, dependent on the rate of parameter change of the stimulus [39]. The cerebellum receives and triggers information from the vestibular receptors, proprioceptors, exteroceptors, and telereceptors in the functional buffer, forming model equivalents of the state of balance at T1, T2, etc., Tn, causing the evolution in the center of gravity's motion toward the central area of the supporting plane's critical curve. When the pyramidal tract is activated by the control sequence of conscious movement, especially when there is a significant shift of the center of gravity, it activates an involuntary, multi-muscle sequence of movement, resulting in balance correction [27].

4. Model and outline of balance mechanisms

The simplest model describing standing posture is the inverted pendulum model. According to it, stability in standing position requires data regarding the position of the upper end of the pendulum (head), as well as monitoring the rake angle relative to the supporting plane. The main mechanism is the proprioception of

pressure distribution of the ankle joint surfaces, changes in lower leg muscle's length and tension, as well as angle changes between axis of the foot and lower leg [40].

Balance loss prevention is effective provided that the nervous system is able to recognize in less than 70–100 ms, the characteristics (mainly direction and force) of a destabilizing stimulus, and raise a competent engram containing a set of drivers for adequate muscle synergy (rapid coordinated movements compensating instability), which would restore synergy [41]. The speed of the motor reaction (which restores the balance) to the stimulus decreases in proportion to the number of alternative patterns of motion behavior, existing in subject's memory. Hence, the adoption of a specific position (bending body forward) limits the choice of a large number of possible alternative movement patterns, reducing time of a proper coordination scheme to access the motoneurons of the pyramidal and extrapyramidal tracts [42]. It reduces the time to generate a motion sequence, which corrects the displacement of the center of gravity outside the critical curve of the supporting plane, increasing the stability. This behavior can be seen in young people, walking on an unstable surface (adaptation), or in the elderly, even on a stable surface (involution). A strategy for (slightly disturbed) balance recovery in subjects standing on a stable surface has been described, where corrective sequence begins with the contraction of the ankle joint muscles (ankle joint strategy), as well as another strategy, in people standing on a narrow ground, which begins with thigh and trunk muscle contractions, and further includes lower limb muscles (hip joint strategy) (Horak, Neshner). The third way for balance recovery is the body from falling down (step strategy) (Nesher) [20].

5. The confrontation of models with the real neuromuscular system of insects

The anatomy of the insect's locomotor system includes all elements described by biomechanics, i.e., limbs, whose rigid elements are combined in a flexible and repeatable manner, with a certain number of degrees of freedom and muscles, with a strictly defined topography of attachments. This design makes it possible to create simple and clear vector diagrams of internal forces, as well as easy, quadrosopic marking and registration of insect anatomical parts, in particular limbs. Compared to vertebrates, the structure of the nervous system in insects is also easy to read, ranging from the neuromuscular junctions, sectoral coordination elements, to the central nervous system. These features create a good chance of learning the full standard species topography of neuron and neural tract clusters and, with its help, determining the list of simple and complex reflexes and understanding their functional foundations. The listed anatomical advantages and high availability of these animals make them particularly useful in the study of parametric motor-behavioral standards, which are the starting point for the next stage, namely, modeling of elementary and complex reflexes, or holistic models in the information space, e.g., neural networks. Particular attention should be paid to basic research regarding:

1. Maintaining balance in the standard position while performing individual movements and walking
2. Creating basic, complex, and systemic models of motion control [43]
3. Reasons for making a movement [44, 45]

4. Modeling of movement in a simple network of an insect's ladder-like nervous system [46]
5. Spatial orientation [46, 47], based on optical (sun, moon) [48], acoustic [49], and magnetic markers [25, 50]

6. Standards of insect motility: an area of inspiration for robotics

The movement coordination schemes obtained in animal studies are an inspiration for the construction of control algorithms in robotics [51, 52] and prosthetics, which supplements the functions of lost limbs [53, 54]. Equipped with receptors, a simple nervous system of an insect probably allows to define the internal state of the body against the background of a model composed of environmental parameters registered by telereceptors, using projection, symbolic coding, and actions on models, which are an electro-resonant representation of the real phenomena [55–57]. Is it possible, then, to integrate spatial multi-receptor models in simple insect neural networks [58, 59]?

7. Biomechanics in the chain of driving phenomena and movement consequences

The ability to maintain balance and the ability to navigate in the outdoor based on specific markers, including the sun, have been well established in simple nervous systems of insects [60]. However, referring to the earlier discussion, human physical activity covers a broad set of behaviors related not only to maintaining balance but also to the locomotion specificity, facial expressions, speech, and voluntary movements of varying complexity. A stable posture is a prerequisite for the majority of voluntary movements, locomotors, and creative activities. The describable human body motion should be treated as a chain of mutually coupled procedures: perceptive, decision-making, control, motor, and systemically interactive and correlated with internal and external reference system. The biomechanical (dynamic) description is a set of parametric sequences of time-synchronized shift vectors of specific marker points [61, 62]. Movement anatomy should be recorded and evaluated in full anthropomotorical context, at least in four categories:

1. Biomechanical, taking into account the range of joint motion, the balance of motion vectors, the muscle strength, and the muscle tone
2. Coordination, understood as the evaluation of the speed and precision of the observed movement patterns
3. Sensory, regarding the sense of the body setting in space and direction of movement, as well as body orientation in relation to the gravity arrow
4. Psychomotor, analyzing the impact of emotional state and psychopathology on the parameters of vector motion analysis

Practical attempts undertaken by the authors in this regard have been successful [63–65].

Adopting an upright position is a reflex action, based on evolutionary and ontogenetically reproduced postural reflexes. Evolution has created a universal movement calibration system using a gravity arrow available all over the planet. The resulting habit of referring motion vectors to a universal direction (even in the darkness) is one of the last stages of mastering and improving motor skills, which allow for a multiple repetition of motor task in a similar manner without involving the consciousness. In children aged 7–11 years, there is an escalation in the development of balance capacities, which is probably never repeated again. The manifestation of unconditional reflexes in this period induces the child to experiment with motion and consequently leads to the formation of individual conditional reflexes, then dynamic stereotypes, and eventually motor habits. Due to the fact that a little later, between 11 and 13 years, there is a period of temporary stagnation or even partial regression of internalized behaviors, it is very important for schoolchildren to have a well-thought-out training, focused on developing coordination and balance skills.

The main area of research in contemporary anthropomotorics is the search for a motion control model and defining methods of encoding information in these models [6, 66, 67]. Drawing inspiration from the mathematical description of the methods for rigid bodies, it is worth remembering the significant differences between the machine and a living organism. A machine, described globally or at subsequent stages of the sequence of its components, performs a specific move (always in the same manner), precisely predetermined by the design plan as well as by the control variant chosen. These features are clearly defined by the machine's working element in the number of degrees of freedom, and the applied constraints accurately determine the specificity of the working track, which will be implemented (with the same parameters) for any number of repetitions. Living organisms can achieve a similar kinematic goal, for which they use an interactive sensorimotor procedure; however, in view of the necessity for a greater number of repetitions, they carry out experiments in the field of kinematic path control (from state A to state B). These experiments consist in attempts to reduce degrees of freedom in the movement control procedure, which also means the reduction in the number of muscles involved and energy saving in consequence (Bernstein). Improving the kinematic forms of movement while reducing energy consumption leads to optimization in the species development of living organisms [68].

It is worth adding that after a thorough, cytoarchitectonic definition of a large part of the cortical sensory fields, which have a strictly defined anatomical relationship with the ascending spinal cord pathways and receptors, as well as the cortical motor fields associated with the descending spinal cord pathways and muscle effectors, a research for functional relationships of higher order between different parts of the cortex began [23].

The above processes for the reduction of degrees of freedom, which aimed to optimize human and animal movements, are described by Bernstein in his theory of control levels. This theory seeks to outline and highlight within the central nervous system (CNS) a specific number of hierarchically associated classes of functional creations, responsible for movement creation of certain specificity, which significantly decreases probability of a control error [69]. Gradually, a cause-and-effect relationship of four factors that determine mobility began to emerge:

- a. Excitability (ability to receive and respond to environmental stimuli)
- b. Analysis of the environment and creationism (perception of new motor tasks and the need to solve them, which leads to the development of existing or

emergence of new executive organs, as well as emergence of new formations in the CNS, enabling the creation of new sensorimotor abilities)

- c. Optimization (development of versatile sensorimotor capabilities that enable building new skills in terms of complex motor tasks)
- d. Sensorimotor intelligence (cleverness, artfulness, and agility combined with prospective calculation of motor task in the context of the structures and entities recognized in the foreground and background of the subject's physical environment) [22, 70]

Initially, a good reflection of it was Bernstein's model, consisting of five hierarchically coupled levels of motion control, trying to find constituent components in complex movements: (A) muscle tension, (B) muscle synergy, (C) spatial field, (D) complex activities, and (E) symbolic operations. Such an arrangement partly explains the follow-up functions of the extrapyramidal system, which adjusts the geometry of angular parameters of the body's rigid modules (bones-joints) and the degree of the bond stiffness (joints) and viscoelastic systems (muscles), in order to maintain balance in the gravitational field, regardless the temporary destabilization of one of the modules of the body (e.g., hand) performing a conscious movement [71]. According to this theory, the system of levels is configured hierarchically, from superficial to profound layers. This direction is caused by the integrating function of layers D to E, which stimulate performance of the motor task components without involving conscious attention. For these levels of movement structure, there have been introduced various control models, for example, for (B), Gibson's ecological model; for (C), the hypothesis of an equilibrium point; and for (D), Schmidt's cybernetic model. Moreover, for reality mapping and motion control, levels A, B, and C use sensory code, while levels D and E use symbolic code of motion representations [20].

The introduction of electronic inventions into biomechanics caused an avalanche of new discoveries in the field of motion kinematics, and it became necessary to modify Bernstein's theory, where instead of a static, layered system of control levels, a dynamic model has been introduced, whose subsequent layers overlap to form transition zones. This new feature well explains the fact that the development of individual levels proceeds gradually, beginning with the emergence of new perceptive abilities and only then of new motor skills. It was assumed that the new level of perception may to some extent define the demand for cooperation with the structures having simpler coordination engrams, which may be a factor that powers the development of sensorimotor and control abilities. In addition, it was assumed that, stimulated with need, a lower level of motor behavior organization, having used up all available range of options, may command the higher level to seek for more optimal motor compositions, as it possesses greater associative capabilities. In this model, there is thus a two-way flow of directives regarding functioning, namely, from the top to the bottom (in order to include simple coordination engrams in the complex, three-dimensional diagrams) or from the bottom to the top (in order to adapt existing, underlying motion engrams to the new kinematic situation in a given environment).

In the complex procedure of balance creation, the cerebellum receives and triggers information from the labyrinth receptors, proprioceptors, extroceptors, and telereceptors in the functional buffer, thus forming multi-loop models, which are electric-resonant equilibrium equivalent at T1, T2, etc., Tn. These models are confronted with many equilibrium patterns; they create corrective engrams that

cause the evolution of motion of the body center of gravity to the central area of the critical curve of the supporting plane. When the pyramidal paths are activated by the control sequence of conscious movement, especially when there is a significant shift of the center of gravity, it activates the independent, multi-muscular movement sequence, causing balance correction [72].

7.1 Perception and gnosis

A perceptive-gnostic procedure occurs in the human CNS (and probably in many other vertebrates), and despite the fact it includes projection engrams, simple and complex perceptual engrams, gnostic engrams, model intentional engrams, and decision-executive engrams, it is not available for measurement systems of classical biomechanics. In this procedure, in a specified period of time, stimuli are projected from proprioceptive receptors (strain gauges, located in tendons, muscles, and ligaments), exteroceptors (skin sensation), and telereceptors (balance organs—gyroscopic accelerometers, retina, eye receptors). In areas of the sensory cortex, anatomically associated with the appropriate type of receptors, electric-resonance, loop equivalents of phenomena recorded by the receptors are created, namely, projection proprioceptive simulation, projection exteroceptor simulation, projection telereceptor-gravitometric simulation, and projection telereceptor-visual simulation simulator. During this time, cognitive processes also occur, referring the resulting projective equivalents to the appropriate pattern bases, resulting in the creation of gnosis, or engrams with the meaning defined for the subject.

7.1.1 Resonance functional integration model

Illustratively, one could call these cerebral, loop-electro-resonance equivalents of phenomena recorded by receptors, for example, proprioceptor-cognitive simulation, exteroceptor-cognitive simulation, gravitational-cognitive simulation, visual-cognitive simulation, and auditory-cognitive simulation. The three-dimensional association on the common timeline of local, organ-specific electro-resonance models of receptor perception and gnosis results in the creation of a conscious, multi-level conjugated cognitive simulation, which is a representation of a body model integrated into the model of the environment, with particular emphasis on sensory receptor density zones within the eyes, mouth, tongue, and fingers. Corrected by gravitational and geometric markers of the environment, model equivalents of sensory phenomena in the cortex of the brain give the possibility of reflex orientation of the head and long axis of the trunk and extremities in relation to the gravity arrow. The first step to gaining the awareness of being is the perception of the model presented above, determining the geometrical features of the shape of one's own body and the environment, as well as proportional relations between the elements of the environment and the body. Therefore, the model gives a sense of the shape and integrity of the subject's body functions in relation to the three main space vectors and components of the internal environment.

It is worth adding that the conditioning of the emergence of consciousness, the subtle state of simultaneous, inter-center synchronization for the cortical projection and gnostic structures of the brain, requires an independent timing system that determines the excitation (specific resonance frequency) of the simultaneous activity of specific brain areas, constituting the electron resonance generating neural medium in a given time-interval loop of currently interfering components of a conscious being. In the model proposed by the authors, the timing system, using a specific, unique frequency, synchronizes interference groups of neurons to a synchronous electrical activity. A spatial, three-dimensional, subtle interference space

is created, composed of variable electric fields of neurons, for which the criterion of integrity in relation to other (surrounding) nerve cells is a specific resonance frequency. An important criterion for the functioning of consciousness, in terms of the clock frequency of the timing system, seems to be the limiting frequency conditioning the overlap of the descending edge of the dying pulse on the leading edge of the next pulse. In the proposed model, there is a resonant coupling with a set of cortical, projection-gnostic representations of specific receptors or decoupling, which allows the transfer of conscious attention from one area of receptor gnosis to another.

The association of internal reference system parameters with external reference system parameters in a synchronous manner with the internal awareness timing system makes it possible to define parameters for the last in the sequence of a motion event—the endpoint controllability [71]. It seems that the registration of the end position signal for the motor coordination engram (which currently has exclusive access to the neural space of the pyramidal pathways) releases him from the position of a leader and activates the mechanism of changing the engram, by way of competition or probabilistic autocreation [73].

7.2 Decision-making procedure

As already mentioned, an important element of the consciousness model is the qualitative recognition of the specific features of the model projection of receptors, based on their relation to the relational database in the memory of the subject and after obtaining the conjunction—recognized as specific structures or phenomena. Perception allows to create geometric relationships between one's own body dimensions and the elements of the environment, as well as emotional relationships in relation to one's own body and its relationships with other subjects and the surrounding structures [74]. The decision-making procedure is based, *inter alia*, on the recognition and classification of surrounding objects in terms of the possibility of their use for the implementation of a specific task. The predefined gnostic parameters determine the structure and range of operation of the seeking system in order to isolate an adequate executive engram, characterized by a stable structure [75].

This involves a whole range of applicable motor strategies that aim to solve specific motor tasks. The brain has or, in a probabilistic dimension, creates a number of alternative strategies for sequential-functional control of muscle groups, which are concepts for solving a planned vision of a kinematic situation [6]. They are created as intentional models of movement that compete for access to the area in control of neuromuscular system in the motor cortex. The neural network makes a directional selection of models, using (as criteria) parametric data acquired from both exterior and interior of the body, choosing the most optimal algorithm in a given kinematic situation [71, 76]. Once given the priority, the selected model becomes an engram of motion creation and takes over the control of the motor cortex, thereby yielding a functional access to the pyramidal tract [77–79].

The control procedure, which is an engram containing a set of time-oriented motoneuron control procedures, is sent efferently through many parallel pyramidal pathways, stimulating the muscles to a conscious, coordinated movement [80, 81]. Motor procedure—the stimulated part of the muscular system—derives energy from the stored high-energy phosphates only in the first seconds of contraction, and further maintenance of physical activity depends on the efficiency of stimulating the Krebs cycle oxidative reactions, as well as efficiency in the removal of the waste products. The above example gives an idea about the interference depth of kinematic stimuli in the body's molecular phenomena. The interactive procedure systemically affects the biomechanical consequences of intentional movement that

could threaten the balance of the whole body. This procedure forces involuntary, follow-up reflexes from the extrapyramidal system, which modulate skeletal muscle tone in different parts of the body, allowing to maintain the balance and constant direction in relation to the gravity vector. A living organism, in contrast to a comparable (in terms of size) and stable (in given circumstances) crystal structure, is a visco-elastic body that changes its characteristics locally, rather than in a way that would be optimally adapted to the forces acting from the outside. Every kinematic situation, which can be described using a simple marker geometry, has a qualitatively different way of linking active information conveyors (nerves), energy converters (muscles), and the blood distribution, which conditions the efficiency of locally intensified metabolism. Local blood distribution profile is connected with ion concentration changes, which by means of the changing tissue resistance, impedance, and magnetic induction influence the sensitivity of the skin sensors. These parameters can be registered using electrodiagnostic methods, such as ECG, EEG, EMG, ENG, and EEA. It can therefore be assumed that each of the organ pairs existing in a living body, despite their high degree of structural and functional autonomy, functions in an information-coupled way through mirror elements of the nervous system and also in a hormone-distribution-coupled way, realized through the vascular system. In order to obtain a complete dysfunction image, it is therefore not sufficient to merely evidence asymmetries in the goniometric tests, as neurogenic, vascular, and immunological causative factors should also be taken into account.

7.3 Control strategy

One of the control strategies aimed at maintaining the general symmetry plan within a pair of organs is their individual endeavor to develop their own existence, which manifests itself in the competition for access to the distribution of nutrients and a tendency for constant reconstruction and redevelopment. In case of damage in one part of an organ pair in the nervous system, at least two basic survival strategies are launched, the first of which consists in intensification of the vascular perfusion and activation of neuronal paracrine secretion, conducive to hypertrophy and hyperplasia of cells in the damaged organ. The second strategy consists in increasing the metabolic efficiency of an intact organ, increasing its contribution to maintaining steadiness of parametric balance at the central level. Organ reflexes for the first strategy are located at the level of the lowest spinal cord integrators and for the second at the level of high spinal cord integrators and hypothalamus [82, 83].

The algorithms shaping motor and metabolic coordination in a living organism are interactive, held under the form of the convergent or opposing oscillations around certain equilibrium points. The extent of this oscillation, being the body's response to the changing environmental stimuli, depends on regulatory efficiency on kinematic, computer, and metabolic level of the system. A young organism, not having many coordination engrams, reacts cautiously, using a large number of oscillations with high parametric amplitudes, trying to optimize to the equilibrium points. A mature organism, having a shaped profile of movement strategies, adapts its behavior to the situation a lot faster and moreover in a balanced and elegant manner.

Cellular homeostasis manifests itself by an individual cell's ability to develop functional states with parameters that pose no threat to the system itself. Its higher level—the tissue homeostasis—is a feedback of many metabolic oscillators, whose plasticity and tendency to minimize the number of energy transformations ensure consistency of the structure. The main tasks in this regard include the temperature and ion composition stabilizing, the regeneration of the stroma, data mediums and

enzyme systems. In emergency states, the majority of chemical reactions in a living cell can occur at some distance from the optimum; however, the thermodynamic efficiency of a given transformation decreases in such case. The amount of energy obtained per a substrate mass unit diminishes, with a significant increase in the production of waste products. On the organ level, such a situation is identified with the developing disease process, in which a large role is played by the control disorders.

A prolonged dysfunction affects the structure of the individual cells or their groups, leading to the reduction in their functional reserves and slowing their recovery, with a steady increase in the rate of the waste substance accumulation. The conjunction of these processes causes the system to reach the control point, trespassing which starts an irreversible process of the apoptosis. Persistent regulatory metabolic disorders can lead to permanent organic changes. Information from skin, muscle, tendon, and visceral receptors regarding the influence of the environment on the body, through the ascending paths, reaches the central nervous system, where it is recorded and analyzed. Depending on the final response to the stimulus at the level of the core, hypothalamus, or cortex, the body reacts with an autonomic reflex or conscious action. In the case of conscious actions, it can be a deliberate motor reaction, while an example of a reflex follow-up reaction is the accompanying movement of the tension of other skeletal muscles, ensuring the body's balance. Autonomic reflexes occur without the participation of consciousness, enabling, for example, automatic glycemic control, symmetry of blood distribution in micro- and macrocirculation, or regulation of endocrine gland secretion. This often causes the subtle molecular response to environmental stimuli.

8. Modulation of the body motor parameters

There are many factors affecting the precision of the targeted and follow-up movements such as fatigue [84]; emotional conditions [85]; mental disorders, such as depression and schizophrenia [86]; postictal conditions [87]; extreme sports [88, 89]; and accidents.

Pain modifies the body movements in a variety of ways. Being an alarm reaction, in the first place, it leads to the reduction in the range of motion along pain-causing, collision trajectories, compensating them by the development of nonphysiological or parapsychological paths, known as the asymmetric profile of dysfunction. Unilateral reduction in the amplitude of motion, along with compensatory increment in another, usually symmetrical area of the body, disturbs smooth, alternating symmetry of muscle work. Virtually every clinical problem that is directly or indirectly associated with the gait function affects the symmetry of foot, knee, and spine load and consequently the degree of their functional and adaptive reserve utilization [90].

The consolidation of the asymmetrical compensatory movement pattern leads over time to more or less advanced anatomical modifications, including muscle, joint, tendon, and ligament remodeling and even remodeling of the bone structure. These changes are noticeable not only due to the use of advanced imaging techniques, such as CT, MRI, and PET, but also on classic radiophotography images. The problem is only that in the medical community, because attention is still not being paid to looking for the causes of apparent asymmetries. A good example would be an X-ray of both femurs, one of which has a clearly thinner cortical layer. Radiological descriptions rarely suggest that one of the patient's legs is shorter and that most of the body weight (>50%) is transferred to it, which results in remodeling and thickening of the cortical bone layer [91]. The evolutionally accumulating experiences of species that, apart from the rigid behavior of the hypothalamus in

the cerebrum created the seeds of abstract thinking, tend to quickly expand the strategy of survival in the environment by joining simple unconditional reflexes—complex sequences of behavior aimed at classifying the environment into neutral, health-promoting areas (vegetation, water reservoirs, mineral deposits) and clearly hazardous (e.g., deposits of toxic substances).

8.1 Elements of the movement metrology

The symmetry of the structure and function of the basic elements of the human body remains in a close cause-and-effect relationship with the symmetry of the structure of the nervous system, treated as a control system, as well as the vascular system, which is in fact a supply and control system for the cellular stroma. Therefore, it can be assumed that each of the organ pairs existing in the living organism, despite the high level of structural separation, functions in an information-coupled manner by means of mirror elements of the nervous system, as well as in hormonal-distribution couplings implemented through the vascular system. The balance of the neural network conducted in subsequent integrators of the spinal cord and hypothalamus, in terms of controlling the distribution of signal and nutrients, including the mechanical and energetic loading of pairs of twin organs, allows their maintenance in a state of functional and anatomical symmetry.

The macroscopic effects of maintained symmetries (especially in the geometrical range) currently belong to the basic criteria for assessing the condition of the musculoskeletal system. However, using the bioengineering assessment of the disease, which occurs with one limb dysfunction, it can be presented as asymmetries of individual parameters or parametric sets, not only regarding the location of markers of body movement in 3D space but also muscle strength, blood supply, resistance, temperature, and skin sensitivity to stimuli, while the numerical determinant of these asymmetries decreases from unity to 0, as the dysfunction increases in the course of the disease and increases again (to values close to unity), in a manner proportional to the disappearance of the symptoms of the disease [92, 93].

In this context, it is worth paying attention to the need for a reliable, parametric and quantitative estimation (that corresponds with the degree of biomechanical dysfunction of the musculoskeletal system) of a greater number of internal body parameters, whose mutual relationships shape the causative dimension of the noticeable biomechanical asymmetries, as well as the disease-related feelings of the patient. It is worth to note that it is difficult to talk about a proper estimation of the current state, prognosis, and treatment effects, without a reliable estimation of the quantitative parameter. Therefore, methods for objective monitoring of disease parameters are actively searched for. Great importance is attached to diagnostic imaging, pathology, and electrodiagnostics. The criterion systems existing in modern medicine give high sensitivity and specificity of qualitative diagnoses, in particular for diseases with a well-recognized etiology and mechanisms of action. An experienced doctor examining a patient is able to see in his body many deviations, such as compensatory movement profile asymmetries, static kinetic reflex disturbances in the Romberg test, temperature and humidity asymmetry of limbs, difference in skin sensitivity to pain and touch, and asymmetry of limb mobility and reflexes; however, he has a difficulty in parametric and numerical estimation of the characteristics of his observations. Estimated methods still exist in the practically used scope of locomotor system assessment, based on interactive, subjective relations between the patient and the doctor, such as the older Lovett scale, visual analog scale (VAS), or newer quality of life scales [94, 95].

9. Medical examination

The metrological dimension of daily medical examinations of the musculoskeletal system is usually limited to the use of simple measurement techniques and tools, due to the difficult access to expensive, advanced measuring technology. In addition, although there are many sites with advanced quadrosopic and strain gauges for assessing and recording biomechanical parameters, their presentation and data collection systems are usually incompatible on an inter-center scale.

The first element of this procedure, an interview, organizes knowledge on the subjective symptoms of the patient. The study design is layered, because it begins with a general health assessment, and delves into the area of details that are specific for certain organs, so it is relatively easy to reduce it to a survey test, allowing for an approximate quantitative assessment. The quality of life rating scales, anatomical-functional syndrome assessment scales, and pain assessment scales have gained in importance here. The credibility of this information depends on:

1. The level of intelligence and education of the patient
2. The specifics of a physician's contact with the patient
3. The general condition of the patient, in particular the duration and severity of the disease
4. The level of intelligence of the patient, which determines the clarity of the message
5. Patient's current attitude, modifying expression towards aggravation or dissimulation
6. Existence of nonmedical intention (desire to obtain compensation or disability benefits)

The doctor's education, clinical internship, and experience as well as his condition on the day of the examination determine whether the collected information will be used as an inspiration for a series of diagnostic associations.

The physical examination is an assessment of the patient's state of health with the use of the telereceptors (eyesight, hearing, smell) and extroceptors (touch, heat, cold, movement) in palpation. The next stage of the study is the use of minimally invasive stimulations in the form of tactile and tactile stimuli, provocative tests, or simple measurement tools. Subsequently, tests are carried out using a goniometer, plumb line, and linear bearing, which allow simple numerical approximations, unfortunately often unrepeatable, due to the fact that every physician introduces some alterations (based on his/her own experience) into the measurement standards. In practice, it translates into introducing one's own interpretations or minor methodological mistakes, specific for one's habits referring to measurement position and the method of the measurement tool's application. These phenomena, provided that patients are examined by the same physician, generate a uniform and distinctive profile of system errors that are fairly easy to eliminate, but when these patients deal with other doctors, they are confronted with a different interpretation profile of the measurement principles (system errors). The overlapping of different approaches to accomplish the same measurement task often leads to the interpretation differences, not only in terms of quantitative assessments but even of the qualitative criteria [61].

10. Metrological engineering techniques

Taking into account the above issues, the pursuit of professionalization in the measurement process gains extreme importance, which can be seen in the works of many authors, concerning the static features of the spine using the projection moire, axial spondylometry, as well as changes of these characteristics in various clinical conditions. Much attention was paid to the assessment of the motion range (SFTR), balance, and gait analysis carried out using contact and photogramometric methods. Joints are an area of particular interest—in clinical practice they are most often subjected to endoprosthetic surgery, i.e., knee, hip, shoulder joints, intervertebral discs or other elements of vertebroplasty, and even the joints of the fingers. An interesting combined research began, concerning the synergy of dynamometric tests, the range of foot movement and strength of lower limb muscles, and gnatosomal analyses. There are also attempts to model complex limb functions based on motion measurement data and EMG signals. Measurements using bioengineering techniques have a great impact on the development of clinical metrology. They have many advantages, such as (1) standardization of the measurement conditions (measurement track in particular), (2) repeatability of the body stimulation scaling parameters using electronic systems (3) repeatability of scaling of the measurement parameters, and (4) stability of the calculation and result-interpreting criteria. Noninvasive recording techniques, consist in resting or functional, but contactless monitoring of vital functions, based on registering parameters that are spontaneously emitted by the body, such as infrared radiation (pyrometry, thermography), electric field (electrography), or magnetic field (magnetography).

Contact recording techniques consist in applying a sensor to the skin surface, in order to establish physical contact (often galvanic as well). The skin surface changes a number of its properties depending on the symmetry and specificity of the processes taking place in the internal organs; hence, the registration of parameters at specific points of the marker will give clear information about the phenomena occurring in the internal organs (e.g., thermometry, ECG, EEG, EMG). The essence of measurement techniques is diverse, depending on the degree of invasiveness [93]:

1. *Bilaterally interactive test*, in which the doctor affects the patient's body with a mechanical stimulus that is hard to repeat (e.g., pricking the skin with a probe or strike) and then the patient makes a subjective response assessment, based on which the diagnostic conclusions are being drawn.
2. *Unilaterally interactive test*, in which the doctor is replaced by an electronic device that generates parameterized and repetitive stimuli while the patient subjectively determines their perception threshold (e.g., palestesiometry, audiometry).
3. *Parametric telemetry test*, in which parametric responses of the patient are recorded—they are based solely on the parameters spontaneously issued by the body (thermography, electrography, magnetography).
4. *Parametric contact test*, involving, for example, fixing a sensor on the body (or unipolar group of sensors), which provides information on selected parameters of the body.
5. *Bilaterally parametric test*, where the body is influenced by a reproducible, parametric stimulus generated by the technical device (which can either

remain in physical contact or else operate contactlessly) while the evaluation takes place outside the sphere of the patient's consciousness, through the system of sensors registering involuntary vegetative reaction parameters.

6. *Invasive registering techniques (A)* that consist in making (in relation to the examined body) energetic extortion as well as recording and interpreting effects of this extortion in the form of (a) rays reflected off the surface (photography), (b) rays penetrating the object (X-ray, CT images), (c) the object being penetrated by the magnetic field (NMR), and (d) the object being penetrated by the stream of ultrasounds (USG).
7. *Invasive registering techniques (B)* that consist in introducing into the body complex chemical compounds, which on one hand have affinity to specific body structures and, on the other, contain a substance that emits radiation that penetrates the coating (usually gamma)—this emission is recorded by the external recording system (scintigraphy, gammagraphy, single-photon emission computed tomography (SPECT)). Based on the above emission, a spatial reconstruction of the organ image is prepared (based on areas with isotope concentration).

11. EBM

A huge problem that is still present in movement studies and physiotherapies is the tendency to look at the multidimensional profile of the patient's suffering and dysfunction through the prism of a narrow specialization, causing multithreading and lack of synergy in procedures related to the diagnosis and treatment of a complex locomotor dysfunction. In this context, a complex biomechanical, psychophysical, and clinical problem begins to be seen as the sum of some separate sequences, which are diagnosed and treated fragmentarily in the narrow ranges of specializations of the successive therapists.

It leads to an absurd situation, in which a pain and dysfunction problem is being taken care of by subsequent specialists in physio- and kinesiotherapy and finally in biomechanics. Based on their own experience and simple measurements, they assess the patient's condition and plan a simple treatment program, mainly in the aspect of symptoms and function, not having a full insight into the interpretation of the results of advanced diagnostic tests. Diagnostics, in turn, is carried out by a team of doctors, who have direct contact neither with a variety of procedures in applied physiotherapy nor with their effects. As for issues revolving around the experience of pain, especially against the background of the patient's individual psychophysical characteristics and predispositions, they are estimated by the psychologist, who is deprived of a broader knowledge of the details of diagnosis and therapy specifics.

In this context, there was a need for a systemic change in quality, and thus also the effectiveness and image of modern physiotherapy, beginning from function in analogy to the principles of EBM presented above, as evidence-based physiotherapy (EBP). The trend initiated a few years ago was reflected in the literature, in the form of interesting publications, displaying various aspects of this issue. One of the first, conceptually well-structured works was a manual [96], then a collective work [97], which postulate that a physiotherapist performing direct, manual diagnostic and rehabilitation activities in a patient, should use the results of advanced clinical diagnostics to clarify any doubts arising from direct observation of the patient. In 2001, the World Confederation of Physical Therapy (WCPT) Expert Meeting on

Evidence Based Practice in London 2001 was founded in London. An important initiative here was to create a PEDro system database accessible via the Internet.

In this new approach, EBP is a collection of clinical procedures that aim at the best possible, holistic use of the therapist's clinical experiences, supported by (verified and available in practice) scientific evidences of image, laboratory, and functional and psychological diagnosis, whose application and integration in one personalized clinical picture increase the effectiveness of medical procedures and patient's safety in the process of the musculoskeletal system's diagnosis, shaping the highest possible level of physiotherapeutic treatment [97]. It can be noticed that the presented definition is quite convergent with the Polish model of the rehabilitation team, promoted since the 1970s (Milanowska, Dega), which uses the consular way of disciplinary knowledge of a rehabilitation doctor, physiotherapist, psychologist, and social worker in order to find a comprehensive solution to the problem of motor organ dysfunction in a medical, psychological, rehabilitation, and social aspect. The cited textbook is particularly recommendable due to the fact that the authors have made a very comprehensive summary of the existing literature on the subject, outlining a very clear picture of the issue. Thus, EBP is shaping a directional model for the development of new science of movement disorders, which are the essence of many medical and physiotherapy specialties, aiming at replacing the currently dominant profile of the assessment of movement disorders implemented by means of distributed sequences, narrowly specialized engineering research, and general medical procedures for the creation of multidimensional and a personalized image reflecting the tangle of causative problems of pain with parametric disorders of biomechanics of movement, combined with metrology of psychological and social consequences.

It is therefore of the utmost importance that the professional evolution of specialists dealing with the musculoskeletal system does not stop at specialized, narrow clinical, or metrological competences but aims at increasing interdisciplinary competences, which will result in the ability to perceive parametric body movement disorders against the background of causative phenomena and above all their adaptive and clinical consequences. In such a new situation, a physiotherapist with broadly formatted practical and theoretical knowledge will not only receive but will also be able to use access to team knowledge, including clinical information on the etiology of the disease, as well as to the results of detailed imaging and clinometric tests. The planned treatment strategy will gain a new, more pragmatic parametric foundation, which in addition to diagnosis offers the possibility of metrological supervision of the effects of therapy, including psychological clinimetry. It is important to remember about the changes in the patient's psyche who is suffering from pain, as well as limiting the implementation of his/her priorities on personal, professional, and social grounds. It is also very important that the technical specialist who formulates the equations of movement does not limit his interest only to the movement of markers in three-dimensional space or tribological relations on the rolling surfaces of the joint, but be aware of the causative phenomena of movement, as well as various consequences for specific parametric intervals. Extending technical knowledge with a biological dimension will certainly result in the improvement of existing and the use of new mathematical applications.

12. Quantitative assessment of the observation

The ability to make an effective, quality diagnosis of the patient is a kind of subjective and highly individualized diagnostician's skill, which combines the elements of systemic, scientific knowledge with acquired experience and intuition into one

coherent system. During the professional development period (of a physician, for instance), this trait evolves as a result of one's dominant character, the amount of acquired theoretical knowledge, and the number of known clinical cases. A unique element—human nature—is therefore a modulator in the way of perceiving subsequent clinical situations, in particular seeing them through the prism of acquired scientific knowledge and gradually collected capital of experience.

Many years clinical experience has been reflected in the creation of more and more specific criterial systems, being a scientific generalization of practical observations of many generations of doctors. These systems provide high sensitivity and specificity of diagnosis in terms of quality. At the moment it can be said that for the diseases with well-known etiologies and mechanisms, criterial systems do serve their purpose. An experienced doctor, while examining a patient, easily sees the qualitative characteristics of compensative asymmetries in patient's profile of motor dysfunction. For example, he/she notices asymmetry and direction of compensation in statokinetic reflexes in the Romberg test, draws attention to the asymmetry in the SFTR measurements, differences in temperature and humidity of the limbs, differences of the skin sensitivity to pain and touch, and asymmetry of myotatic reflexes, but **has difficulties in estimating the quantitative characteristics of his/her observations.**

To sum up, one of the major problems of musculoskeletal medicine is the difficulty of a reliable, quantitative estimation of biomechanical parameters of the asymmetry of the patient's adaptive dysfunction profile and the subjective dimension of his suffering that occurs in the course of a qualitatively diagnosed disease. It should be remembered that without a reliable assessment of the patient's initial biomechanical parameters, it is difficult to talk about proper assessment of treatment effects and prognoses. Currently, in the evaluation of the musculoskeletal system, estimated methods are still in use—they are based on mutually subjective relationship between the patient and the physician, with examples such as the Lovett and WAS scales or (more recent) quality of life scales. Metrology-wise, the use of simple measuring tools dominates and is rarely supplemented with individual cases of only locally available (and usually unique), advanced measurement technology.

13. Clinimetry

Methods of converting specific (but descriptive) clinical criteria (that are specific for different disease units) into the form of bioengineering parameters, which would finally allow for a quantitative monitoring of disease parameters, are being actively searched for. Another question is whether a principle that is obvious for the angular, vector, and time parameters used in biomechanics can be applied in the description of results of medical imaging, pathology, and electrodiagnostics. There is a lack of a supervisory system that would function as a standard, inter-center way of presenting well-known measurement technologies enriched with a quantitative aspect adjusted to this standard, designed for communication and capable of assimilating new diagnostic solutions to suit the presentation and systemic work.

13.1 Movement marking

An important element of bioengineering research is the correct location of the body marker points, thereafter subjected to a static 3D parameterization, with the possibility of tracking, associated with the movement of the parametric drift in the dynamic graphic analysis or in telemetric analysis of radio markers. A characteristic feature of these points must be location stability as a common feature of

individuals that belong to the same species. Thus, a body construction property, acting as a geometrically distinctive feature for a given species, is called the marker point. A convenient starting procedure is to perform the erosion of the body image (loss conversion), in order to expose the main limb axes, at the same time indicating their joint connections (bonds). The next step is to flag the selected markers at the coordinate system obtained and to draw the vectors showing the acceleration, velocity, and direction of motion. The procedure requires a considerable computing power of the computer system.

13.2 The problem of a parametrically incomplete observation

From the diagnostician’s viewpoint, a quadroscope, dynamic image analysis is a very attractive option, since the acquisition of motion geometry parameters is based exclusively on the measurements of patient’s relatively casual behavior, recorded by few cameras. The only nuisance are reflective (or glowing with their own light) markers fixed to the body. The drawback of this solution is a complete lack of information on the causative processes that lead to the motion of the limbs, as well as about the motion results, or, in other words, the kinematic impact of its action on the ground.

The elements trying to fill this gap were two types of contact posturometry systems, the first of which—strain gauges—collected information about the distribution of foot pressure on the ground (in the time domain) and the second, accelerometer analyzers, through a network of sensors located on the limbs, recorded multichannel motion speed and limb acceleration.

Since 2003, the Laboratory of Biotechnology (“LABIOT”) began to construct measuring systems combining both of the above diagnostic features with the simultaneous measurement of the blood flow and even the electrical parameters of the skin and muscles (**Figure 1b**). Parameters registered by the prototypes, which were built according to the above schemes, initially showed little satisfactory repeatability; hence, a strict standardization (markering) of measurement points was introduced. The multithreaded systems corrected this way showed much greater stability and reproducibility of the results. Undeniably it was a technical success, yielding a large number of reliable measurement results interconnected on a common time base. As it turned out, technical success was only a partial solution to the problem

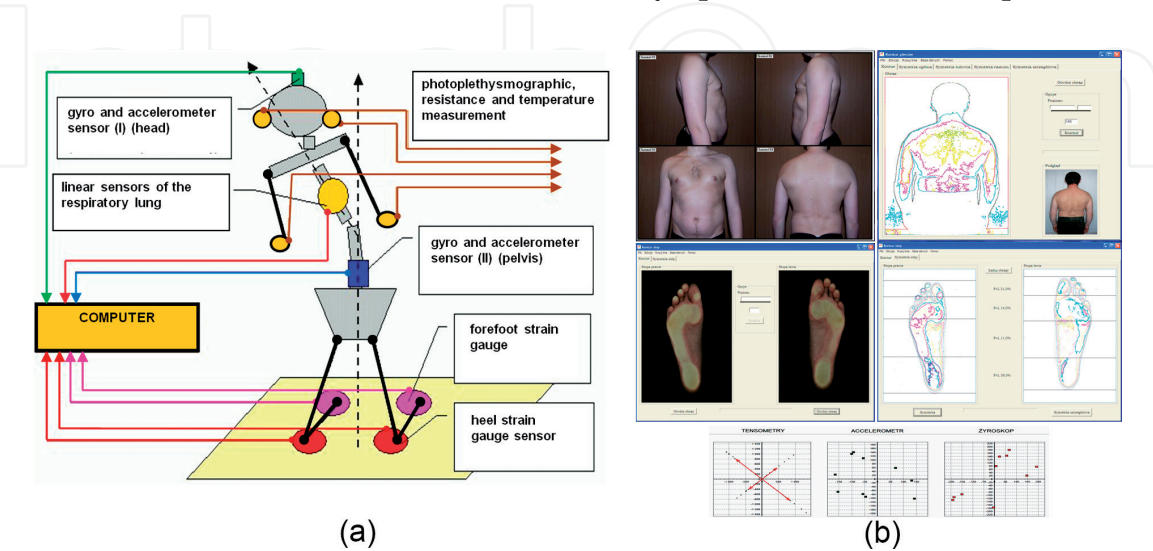


Figure 1. A scheme of the author’s contact posturometry system: (a) built in 2003, which integrates a multichannel system of acceleration sensors with feet strain gauge sensors and sensors registering flows in the blood vessels; (b) numerically recording system (PSB1) quadroscopic-podoscopic, gyroscopic, accelerometric, and strain gauge parameters of the patient’s body, presented at the Rehabilitation Fair in 2019.

and was not reflected in the clinical aspect, as numerous and accurately registered measurement parameters were presented in completely different physical units and thus were difficult to correlate and even more so to interpret [97, 98].

There is yet another question that arises—how to understand the body’s dynamic state at various movement stages described by multiple numbers, whose calibration systems are anchored in completely different dimensions and physical units? Is there a common denominator that indicates the momentary, initial, and final status for such data distribution, let alone a reliable clinical interpretation?

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