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METHOD OF FUNCTIONAL BIOMECHANICAL TESTS

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Abstract: A new method (the method of functional biomechanical tests) to estimate the functional conditions of organs, tissues and human organism systems on the basis of the "dozed" (measured) mechanical actions have been proposed. Some examples of its realization by using the specially designed mechanical strikers are given below. The data illustrating the efficiency of application of this method for screening the population are given as well.

Key words: mechanical action, striker, reaction of human organism, separation of reaction, mathematical modeling, screening

Introduction

As a rule, in studying the biomechanical features of alive organisms the researchers pay the main attention to the problems of strength and fracture (see, for example, [1]). The same tendency takes place in the field of the medical researches as well. At the same time the important problem concerning the study of the nature of return reactions of human organism to mechanical actions for the medical diagnostic analysis has insufficiently investigated. For instance, there is only one mention [2] among more than one hundred scientific reports published in the Proceedings of International Conference "Biomechanics in Medicine and Surgery", which concerns the problem of functional reaction of alive systems on different biomechanical actions as well as the relationship between such reactions and the features of the behavior of alive organism as a whole.

Usually the investigations of mechanical features of tissues, organs and systems of organism are carried out separately, without the consideration of their intercommunication with the organism as a whole. Up to present the exact, metrologically provided methods to investigate the biomechanical features of the parts of alive organism are practically unknown. At the same time biomechanical reactions on various actions as well as the mechanical processes in the organism themselves can include highly useful information concerning the analyzing the regulation processes of vital activity as well as the solution of the problems of diagnostic and treatment of diseases. In clinical practice, the methods of organism condition evaluation based on biomechanical manifestation are widely expanded long ago. For instance, using the method of pulse diagnostic in Tibean medicine [3] the qualitative features of mechanical pulse wave are investigated. The methods of auscultation, percussion and palpation are very popular too. These methods use the mechanical properties of organs and tissues as informative symptoms giving the corresponding information [4]. Besides some functional tests (such as malleus tests to study the pattelaris and radialis reflexes) are broadly used in clinical practice. However up to now all those tests excluding the method of pulse diagnostic and a method of ultrasound tomography (as the introscopy method) are characterized by qualitative indices only. In fact, using those methods we cannot determine the numerical value of effect (producing "by eye") as well as the numerical value of corresponding mechanical reactions. Moreover we cannot distinguish the mechanical part of the reaction from its functional part. This circumstance is of principal importance, since the functional (reflex) part of the biomechanical reaction is highly informative and so it can inform us about the state of regulating systems of alive organism.

From the above mentioned considerations we can conclude that the goal-direct development of exact methrologically substantiated methods of diagnostic on the basis of biomechanical functional tests is a very urgent problem of great practical importance.

The proposed approach

The main point of the proposed approach is as follows. A strictly appointed and exactly measured mechanical action (such as impact, vibratory or quasi-static action) is applied to accurately localized areas of body. And then the return reactions of human organism at given points of body are registered by means of special sensors (detecting elements of displacement, velocity, acceleration, force, etc.). The analysis of the resulting experimental information can be carry out in two directions.

The first direction deals with the determination of the range of mechanical reactions for practically healthy people and for people having disease of different nature. Such determination is carried out on the basis of statistical processing of experimental data. Herewith the possibility to characterize the difference of these reactions numerically by comparison of the values of norm with pathology on the basis of some criterion enables to design standard for known biomechanical test or to create a new standard test.

The second direction is more efficient but more difficult. It deals with the use of the different mathematical models of organism functioning and with the identification of given models. On the basis of cybernetics analogy it is possible to consider the human organism as a dynamic system and to study it using the corresponding mathematical formalism such as spectral analysis, transfer functions (operational calculus), the theory of stochastic processes. Having solved the problem of the identification of dynamic system we obtain the numerical values of parameters of mathematical models and then we need to interpret them as features of physiological norm or pathology. The main difficulty of interpretation is to establish the statistical significant relationships between obtained parameters and symptom-complex of corresponding diseases.

Above mentioned directions of investigations might be called the method of functional biomechanical tests (FBTM). This term is offered for the first time by the authors. It should be noticed that dental-jaw system, the cardiovascular system, the respiratory system as well as the cerebrospinal section of nervous system and backbone are the most perspective objects for investigation by means of the FBTM [5,6].

FBTM and some results

Realizing the FBTM the single step-like effects and/or single impulses can be used as a test actions. The variant of a device for getting the test signals worked out by the authors is a striker with calibrated spring.

The scheme of research of reactions of spine and osseous-muscular systems on calibrated action is shown in Fig.1 as an example of the use of FBTM. The patient in the sitting (Fig.1a) or standing (Fig.1b) position is subjected to the physiological safe dozed test action $h(t)$ in the manner of the shock or the displacement, acting on the support. Appeared mechanical waves are registered by the means of electrical sensors of displacements and velocities, placed on the skull and along the spine of the patient. The signals $S(t)$ recorded by the sensors come to personal computer (PC) for processing and analyzing. The tests carried out on the experimental model have shown the following. The mechanical part of the return reaction of organism is practically completely faded very quickly (in 0.05-0.1 sec after the action) and then the functional (reflex) part of the reaction appears (in 0.15-0.20 sec after the action). Such value of delay of functional part of reaction is supported by known researches in the field of neurophysiology [7,8,9]. Having such time separation of the parts of reaction we can statistically reliably identify the reactions of different groups of muscles with the help of the same sensors. Some more important experimental observation (which is yet to be thoroughly verified) is related with the following circumstances. Both the mechanical part and functional (reflex) part of the organism reaction to the mechanical action are changing due to diseases and corresponding pathologies. This fact can be used in developing the methods to select the patients with respect to the criterion “sick-sound”.

Using the FBTM it is possible to estimate the various pathological changes in the human organism by means of identification of corresponding mathematical or physical models. For example, let us consider the long tube (Helmholtz resonator) as a model of system “skull cavity - spine cavity”. Following this model the resonance frequencies of vibrations will be changed depending on the elastic properties of skull and spine under the sinusoidal action on the support *h(t)* [10]. These properties depend upon mechanical compliance of bones and connective tissues of skull and spine. But the intracranial and cerebrospinal pressures influence on the mechanical compliance. Consequently, the increase (or decrease) of specified pressures leads to the corresponding change in the value of the speed of acoustic waves and their spectrum composition, as a result. Thus it is possible to use the dynamic characteristics of resonator to obtain the non-invasive estimations of above mentioned pressures.

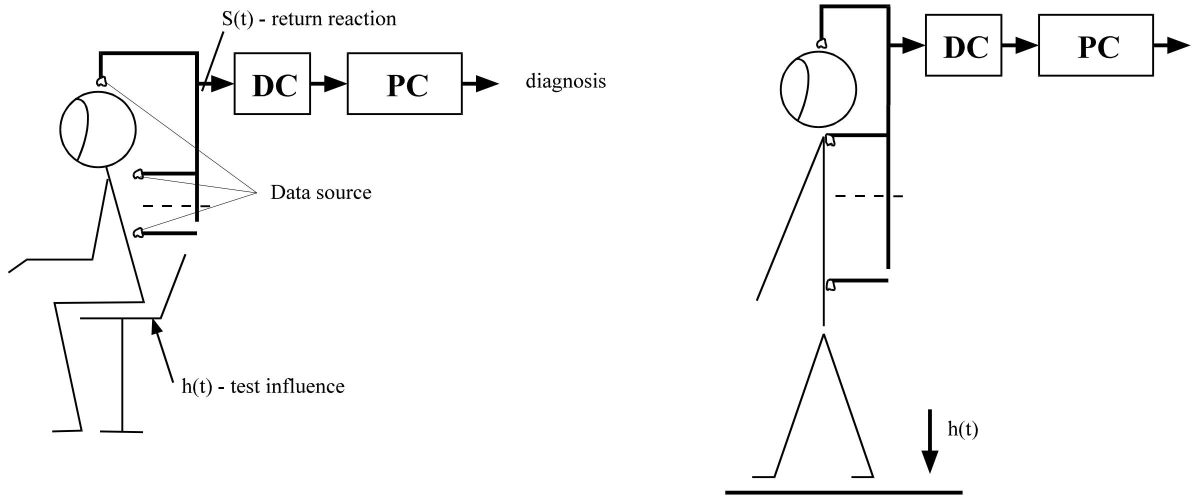

Fig. 1. Scheme of the method of functional biomechanical tests.

The proposing FBTM is most suitable for the express-diagnosis having preliminary nature. (After that more detailed investigations can be fulfilled, which are to be based upon known methods requiring considerably more time-taking and expensive procedures). Such diagnosis makes possible to enlarge reception capacity of clinics producing preliminary screening of patients and thus to increase their profitability. All above mentioned can be applied first of all in dental practice. Coming from this a new manner of investigation of a dental-jaw system (DJS) have been proposed by the authors. This method based on the mechanical testing the DJS is realized in the creation of experimental installation for function-biomechanical tests. (Decision of VNIIGPE on issue of certificate on useful model N 961188651/20 (025148), 24.12.96).

To describe the DJS the authors propose the following electrical analogy (see Fig.2, where for the sake of simplicity the scheme of the only jaw is presented). The DJS may be shown as an ensemble of complex acoustic resistances (impedances and admittances) Z and Y connected with each other by special way. The central nervous system (CNS) is presented on this scheme by the regulator, its entries being connected with receptors R. The outputs of the regulator control the electrical capacities modeling the elasticity of maxilla and mandibula (MM and TM). The electrical analogy is very convenient to illustrate the signal (informative) character of mechanical processes taking place in functing of the DJS. With the help of the given scheme we can demonstrate the effectiveness of FBTM to diagnose and investigate some stomotological pathologies. This can be described by the following way.

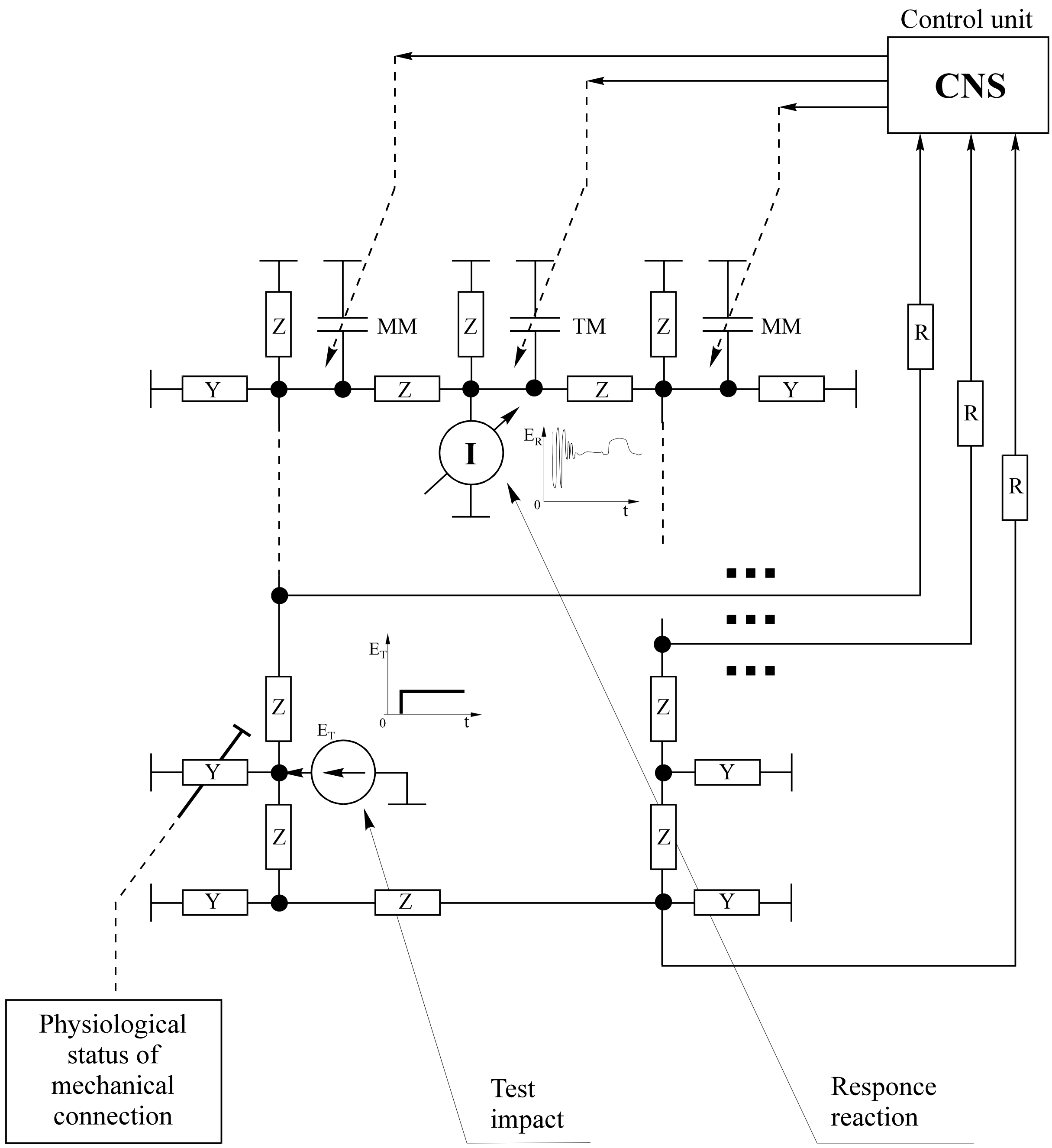

Fig. 2. The electrical analogy of dental-jaw system.

Under the action of the striker to the tooth the reaction of human organist is recorded by the sensorses placed on the forehead and the maxilla. The obtained signals pass to PC for treating and studying the spectrum composition. The analysis of the spectrum enables to find out the correlation between the spectrum characteristics and physiological condition of DJS. For example, the increase of power of low frequency spectrum components indicates the appearance of pathological a periodontal-muscle and pulpe-muscle reflexes [5].

The approbation of the system suggested in clinic has demonstrated the effectiveness of the FBTM both for diagnostics of teeth caries of teethes and for the characterisation of condition of transplanted elements of the DJS.

Conclusions

1. The mechanical processes taking place in alive organism represent the important channel for transmission of controlling information in this organism. Nevertheless quality characteristics of this informative channel have been investigated extremely insufficiently. Therefore, as the first important and imperative step of biomechanical investigations it is necessary to carry out methrologization and standardization of all tests concerned with the mechanical action to the human organism.

2. Electrical analogies of human organism systems can be effectively applied to describe qualitatively the reactions of these systems on the mechanical actions.

3. The preliminary analysis of experimental data obtained on the laboratory installation has shown that mechanical and functional (reflex) parts of registered reactions of human organism can be reliably separated.

References

1. OBRAZTSOV I.F., HANIN M.A. **Optimum biomechanical systems**. Medicine (Moscow), 1989 (in Russian).
2. KOROLYEVA I.N., BULAYEV U.O. The Effect of Vertebral Column Posture on the Motorial Reactions of Upper and Lower Limbs. In: B**iomechanics in Medicine and Surgery**, Vol. II: 510-514, Riga, 1986.
3. TSYDYPOV C. **Pulse Diagnostics of Tibean Medicine**. Nauka (Novosibirsk), 1988 (in Russian).
4. TAREEV E.M. **Internal Diseases**. Medgiz (Moscow), 1952 (in Russian).
5. RUBINOV I.S. **Physiological Fundamentals of the Stomatology**. Medicine (Leningrad), 1970 (in Russian).
6. LYSENKOV N.K., BUSHKOVICH V.I., PRIVES M.G. **Handbook on the Normal Human Anatomy**. Medgiz (Moscow), 1958 (in Russian).
7. LOGINOV A.V. **Physiology and the Fundamentals of Human Anatomy**. Medicine (Moscow), 1983 (in Russian).
8. SHEPERD G. **Neurobiology**, Vol. 2. Mir (Moscow), 1987 (in Russian).
9. SPIVAK L.I. **Knee Reflex: Normal and Abnormal**. Medgiz (Leningrad), 1957 (in Russian).
10. BAKUSOV L.M. **Some Models and Methods of the Wave Hemodynamics**. Ufa Aviation Institute Publishing (Ufa), 1992 (in Russian).

Метод функциональных биомеханических проб

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В клинической практике давно и широко используются методы оценки состояния организма по его биологической реакции на то или иное механическое воздействие. Однако, за редкими исключениями, во всех этих методах отсутствуют количественные оценки и самого воздействия, и ответной реакции организм. Таким образом, первым и обязательным шагом при использовании механических воздействий на организм с целью медицинской диагностики является метрологизация и стандартизация всех применяемых проб. В этом и состоит суть предлагаемого метода функциональных биомеханических проб: строго дозированное, надежно измеряемое механическое воздействие (ударное, колебательное, квазистатическое) на четко локализованные участки тела и (с помощью датчиков перемещения, ускорения и т.д.) количественная регистрация ответной реакции организма в заданных точках тела. Анализ полученной таким образом экспериментальной информации может быть использован как для идентификации математических моделей функционирования организма, так и для экспресс-диагностики пациентов (по принципу «больной - здоровый»). В предложенной авторами реализации метода функциональных биомеханических проб тестовое воздействие осуществляется ударником с калибровочной

пружиной. Испытания на лабораторном макете выявили два характерных обстоятельства, которые можно эффективно использовать при диагностике заболеваний: механическая и рефлекторная части ответной реакции организма на механическое воздействие а) разделяются во времени (рефлекторная часть возникает с задержкой); б) изменяются при наличии патологических процессов в организме. Созданная авторами установка для метода функциональных биомеханических проб зубочелюстной системы прошла успешную апробацию в условиях клиники. Библ. 10.

Ключевые слова: механическое воздействие, ударник, реакция организма, механическая и рефлекторная части реакции, моделирование, скриннинг.

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