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ALGEBRAIC MODEL OF KNEE JOINT STATUS: EXPERIMENTAL STUDY

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ABSTRACT — The rationale behind this paper relies on the fact that the effectiveness of any treatment procedure depends on the reliability of the operational and prognostic medical measurement experiment, which, in turn, relies on the metrological level of all the elements that are part of the instrumental resource.

Given the conditions, relevant is the issue of developing a methodology for selecting measuring tools, which would allow taking into account the cost, the reliability, the metrological as well as other features and indicators of the resource in question.

The purpose of the article is to assess the technical needs for solving problems set in the field of meaningfully defined objects – medical & biological systems (MBS). The solution to this problem can be found only on the basis of formalizing all the components that match the MBS description.

The research value implies the introduction of formal definitions for the anatomical (AnS), physiological (PhysS) and information-energy (IES) situations of a biological object (BO) and assignment of a diagnostic status of BO as a function of AnS, PhysS and IES. In addition, we have defined the principle of identifying the features of the instrumental base on following the basis of assessing the reliability of the physiological system status.

The pragmatic value of the data presented here implies the possibility of obtaining a numerical estimate of an acceptable reliability level that an instrumental resource can offer depending on the assessment of a physiological object sufficient reliability.

The innovation value of this item is related to the introduction of reliability scales for the BO diagnostic status as well as the reliability coming from the instrumental resource in medical measurements.

KEYWORDS — diagnostic situation, physiological system status reliability, set-theoretic model.

INTRODUCTION

Modern personificative medicine uses a high technological method of diagnostics; the treatment is based on using the results of fundamental sciences including constitutional anatomy [1–10].

The effectiveness of any treatment procedure is known [11–14] to be undeniably determined by the reliability of the operational and prognostic medical measurement experiment, which, in turn, is determined by the metrological level of all the elements within the instrumental resource. Besides, the instrumental resource includes equipment that features a significant variety of complexity — from large measurement and calculation complexes to simple one-dimension measuring devices.

In view of that, it is very important to create a methodology for selecting measuring instruments, which would allow taking into account the cost, the reliability, the metrological as well as other features and indicators of the instrumental resource.

Then, there is a need to assess technical needs in order to solve problems that have been set in the field of meaningfully defined objects — medical & biological systems (MBS). Such problems can be solved only on the basis of the formalizing all components that match the MBS description.

Also, it is a known fact [15] that any treatment technology can be described with a potential (required) error [16] to ensure high reliability of diagnosis. At the same time, by the *diagnostic error*, we can take the difference between the achieved value of assessing an individual body organ status or the body as a whole through the measurement process and a hypothetical assessment value that is taken as the average value known for a healthy organ or body. It is obvious that the maximum acceptable error in establishing a diagnosis for an accepted medical technology can be viewed as a *potential diagnostic error*.

An extremely important element in the description of MBS is the MBS status, which is the basis for comprehending a particular diagnostic situation.

Then, the *diagnostic situation* (DS) $M_{diagn\ sit}$ of a biological (biomedical) object is a complex (set) of the anatomical $M_{an\ sit}$, physiological M_{phs} and information-energy states $M_{ie\ s}$ of this object:

$$M_{diagn\ sit} = M_{an\ sit} \cup M_{ph\ s} \cup M_{ie\ s} \qquad (1)$$

The definiteness of the DS assessment is most reasonable when based on the formalization of all its components.

MATERIALS AND METHODS

The *model of the anatomical situation* $M_{an\ sit}$ is a class that looks the following way:

$$M_{an\ sit} = \{M_{an\ syst}, M_{dr\ an\ syst}, M_{an\ phc}, M_{fc\ an}, M_{sp\ an}\}, \quad (2)$$

where $M_{an\ syst}$ is the category model of the anatomical system; $M_{dr\ an\ syst}$ is the definition range of the anatomical system; $M_{an\ phc}$ is the anatomical system physical constant set; $M_{fc\ an}$ is the set of the functioning conditions for the anatomical system; $M_{sp\ an}$ is the anatomical system parameters model.

At the same time, the anatomical situation model $M_{an\ syst}$ is either a graph or a category set. Subject to the definition for a graph (G) [17], its definition range M_{dr} is sets of X elements and a set transformation of G_{χ}, i.e. in this case we are talking about the knee joint elements (KJ) — bones, tendons, and ligaments. The KJ elements attachment points, or fixations stand as the set transformation. The physical constants model $M_{an\ phc}$ are biomechanical indicators of KJ, which offer the description for elasticity, strength, flexibility, etc. The physical constants set model $M_{aph\ an}$ are a combination of anatomical limitations on the mutual position angles for the KJ bone elements, based on KJ bone elements relative motion, on various ligaments deformities. The model of anatomical system parameters $M_{sp\ an}$ is a Cartesian product [7] of KJ parameters that make up the joint function image, i.e. $M_{an\ sit}$.

Physiological situation model M_{phs} is *a class of the following type*:

$$M_{phs} = \{M_{fs\ ph}, M_{dr\ ph}, M_{phc\ ph}, M_{fcs\ ph}, M_{sp\ ph}\}, \quad (3)$$

where $M_{fs\ ph}$ is the category model of the functional physiological system; $M_{dr\ ph}$ is the model of the physiological system definition range; $M_{phc\ ph}$ is a set of physiological system's physical constants; $M_{fcs\ ph}$ is a set of physiological system's functioning conditions; $M_{sp\ ph}$ is the model of the physiological system's systemic parameter.

When detailing the physiological situation, note to be made that the category model [18] of the functional physiological system $M_{fs\ ph}$ is a combination of KJ elements interaction function under external (regarding the KJ) factors. $M_{dr\ ph}$ is a combination of definition ranges for each function of the functional physiological system. $M_{phc\ ph}$ develops from a number of coefficients, indicators, physical constants (that are part of the set), which describe the functions $M_{fs\ ph}$. $M_{fcs\ ph}$ is a limitations combination of function domain, which enter $M_{fs\ ph}$. The physiological system parameter model $M_{sp\ ph}$ develops by the combination of the $M_{fs\ ph}$ function domain.

The information-energy situation model $M_{ie\ s}$ is *a class of the following type*:

$$M_{ie\ s} = \{M_{ie\ syst}, M_{dr\ ie\ syst}, M_{pc\ ie\ syst}, M_{fc\ ie\ syst}, M_{sp\ ie\ syst}\}, \quad (4)$$

where $M_{ie\ syst}$ is the category model of the information-energy system; $M_{dr\ ie\ syst}$ is the information-energy system definition range; $M_{pc\ ie\ syst}$ is a set of the information-energy system parameter constants; $M_{fc\ ie\ syst}$ is a set of the information-energy system functioning conditions; $M_{sp\ ie\ syst}$ is the analytical model of the information-energy system parameter.

Detailing of the information-energy situation model $M_{ie\ s}$ comes from analyzing the category representation. The information-energy situation model $M_{ie\ s}$ is to be expressed in the following way:

$M_{ie\ s} = \{$ G_{SN} — sciatic nerve category; G_{TBN} — tibial nerve category; G_{FN} — femoral nerve category$\}$ $\to (CNS, SN) \leftrightarrow G_{SN}$; $\{G_{TB} = (CNS, TBN)$; $G_{FN} = (CNS, FN)\}$; {humoral categories}.

In view of the above, the complete algebraic model of the knee joint diagnostic status is to be presented as follows:

$$M_{diagn\ sit} = \{M_{an\ syst}, M_{dr\ an\ syst}, M_{an\ phc}, M_{fc\ an}, M_{sp\ an}\} \cup$$
$$\cup \{M_{fs\ ph}, M_{dr\ ph}, M_{phc\ ph}, M_{fcs\ ph}, M_{sp\ ph}\} \cup \quad (5)$$
$$\cup \{M_{ie\ syst}, M_{dr\ ie\ syst}, M_{pc\ ie\ syst}, M_{fc\ ie\ syst}, M_{sp\ ie\ syst}\}.$$

RESULTS AND DISCUSSION

The algebraic model (15) serves as a formal basis to develop a set complex for assessing the reliability of the shaped diagnosis of the status. Note to be made that the status formulas include certain objects (the elements of the physiological component of the common organic system), the relations among them (or interactions), the constants and the conditions for interaction. All the participants in this structure are dimensional and feature a definable error. Then it is possible to find the maximum errors admissible in general assessment of the statuses, known from expert practice. Subject to the methods described in [19], for instance. In this case, we can argue that the maximum permissible errors of the instrumental tools should be no worse than the general status assessment [20]:

$$AK_{exp}(\Delta_{FS}\lambda^*_{exp}) \rightarrow \theta^*_{ach}[\Delta\lambda^*_{FS}] \leftarrow AK_{instr}(\Delta_{FS}\lambda^*_{instr}) \quad (6)$$

where $AK_{exp}(\Delta_{FS}\lambda^*_{exp})$ is the general assessment of the FS status obtained through expert evaluation employing a priori knowledge (AK) concerning this FS activity features; $AK_{instr}(\Delta_{FS}\lambda^*_{instr})$ is the general evaluation of the FS status, which are to be obtained using a priori knowledge (AK), regarding measuring units specifics, and which may be employed through the FS monitoring; $\theta^*_{ach}[\Delta\lambda^*_{FS}]$ is the general assessment of the difference between the desired (potential) error that has been defined by experts, and the error that is maximum achievable through the measuring devices. Moreover, in the descriptions of situations, all the models may contain specific features, indicators, and parameters that have numerical values obtained through earlier studies and may contain some error. At the same time, all functional models are also obtained using approximations with nonideal and imperfect dependencies.

Similarly to [21], AK_{exp} may be presented in the following way:

$$AK_{exp}(\Delta_{FS}\lambda^*_{exp}) = \{ \lambda^*_{exp} = F_{exp}(\bar{\gamma}_{exp}), \bar{\gamma}_{exp} = [\gamma_{\min exp}(t) \div \gamma_{\max exp}(t)], M_{c\ exp}, L_{exp} = R_{m\ exp} \ldots R_{1\ exp}, \{R_{i\ exp}\}_{i=1}^{m}, \bar{w}_{exp}(t)\}. \quad (7)$$

Where λ^*_{exp} is the observed value that describes the physical functional system's behavior, which is base on expert evaluation; F_{exp} is the expert function of the FS comprehensive accepted classical behavior; $\bar{\gamma}_{exp}$ is the vector of expert impact of the FS for defining the response taken by the system; $[\gamma_{\min\ exp}(t) \div \gamma_{\max\ exp}(t)]$ is the change interval that the expert impact has on the FS that is being examined; $M_{c\ exp}$ is the set of external conditions within which the expert study is to be carried out; L_{exp} is the FS expert study methodology; $R_{i\ exp}$ is the i^{th} step within the FS behavior expert study methodology; $\bar{w}_{exp}(t)$ is the probability density for the distribution of comprehensive probabilistic characteristics of the expert study outcomes.

In a similar way we could present $AK_{inst}(\Delta_{FS}\lambda^*_{instr})$:

$$AK_{instr}(\Delta_{FS}\lambda^*_{instr}) = \{\lambda^*_{instr} = F_{instr}(\bar{\gamma}_{instr}), \bar{\gamma}_{instr} = [\gamma_{\min\ instr}(t) \div \gamma_{\max\ instr}(t)], M_{c\ instr}, L_{instr} = R_{m\ instr} \ldots R_{1\ instr}, \{R_{i\ instr}\}_{i=1}^{m}, \bar{w}_{instr}(t)\}. \quad (8)$$

Here AK_{instr} stands for a priori knowledge which concerns the actual FS status and which develops base on special measuring experiment using the selected instrumental tools; $\lambda^*_{instr}(t)$ is a measurable value that is adequate to the system parameter of this particular FS; F_{instr} is the calibration curve that approximates the function $\lambda(t) = f(\gamma(t))$, used for establishing the ideal adequate link between the measurement outcome and the standard impact within the medical experiment; $\bar{\gamma}_{instr}$ is the system parameter accepted for the medical experiment involving measuring tools; $M_{c\ instr}$ is the set of conditions for the medical measuring experiment; L_{instr} is the instrumental measuring procedure implemented via the conventional tool; $\{R_{i\ instr}\}_{i=1}^{m}$ is the i^{th} instrumental measuring transformation within the procedure L_{instr}; $\{R_{nji\ instr}\}_{j=1}^{m}$ is the j^{th} instrumental module that is part of the measuring tool, which implements the procedure L_{instr} adequate to the scaling transformation of F_{instr}; $\bar{w}_{instr}(t) = \{w_{1\ instr}, \ldots w_{m\ instr}\}$ is the probability density for the distribution of the probabilistic characteristics combination, adequate to the accepted measuring tool.

CONCLUSION

As noted above, the effectiveness of any treatment procedure depends exclusively on the reliability of the operational and prognostic medical measurement experiment, which, in turn, is determined by the metrological level of the instrumental resource's elements. The proposed algebraic model for the knee joint status allows defining a method for obtaining formal estimates expressed as the required potential accuracy of the diagnosing assessment for the biomedical object status, to be performed through metric identification algorithms, which allows identifying the borderline errors for the instrumental resource, which, finally, creates the basis for metrological synthesis of medical measuring techniques.

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