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DIGITAL TRANSFORMATION IN MEDICINE: FROM FORMALIZED MEDICAL DOCUMENTS TO INFORMATION TECHNOLOGIES OF DIGITAL MEDICINE

Introduction. *According to the Concept of Ukraine`s Digital Economy and Society Development in 2018-2020, the key components of "digitalization" are the development of digital infrastructure — broadband Internet throughout Ukraine, and the promotion of digital transformations in various sectors of the economy and society, including medicine.*

The purpose *of the paper is to analyze the stages of digital transformation in medicine and the results of authors and their colleagues of the MIS department for the development of information technologies of digital medicine.*

Results. *A generated model of digital transformation in medicine is presented and several main stages of this transformation are highlighted: I — digital transformation of primary medical information; II — development of support systems for the diagnostic and treatment process; III — development of technologies and systems for supporting the physicians` activities with digital information; IV — mobile medicine; V — the digital medicine* *globalization. The method of determining the markers of the functional state of the cardiovascular system based on mathematical models of forecasting and classification with the use of Data Mining is proposed. The method allows detecting and determining the prognostic values of ECG parameters of the CVS functional state for different groups of patients. The developed IT for supporting the processes of receiving, transmitting and storing digital medical images is aimed at ensuring the effective operation of a physician with digital information from various sources: functional diagnostic complexes, digital medical data storage and images using Picture Archiving and Communication Systems (PACS) and cloud technologies. The proposed telemedicine systems theory including the formulated principles of organizing these systems, criteria and methods for analyzing digital medical data has been implemented for elaborating and functioning the Telemedicine Center. It enables to cover the population in more than 20 Ukraine`s regions with qualified medical assistance.*

***Conclusions**. The digital transformation in medicine like any new process takes place with a gradual complication of tasks, methods and means of their implementation: from formalization of primary medical information to improvement of methods of its analysis, transfer and storage to improve the quality of medical care for patients at any point of the world.*

***Keywords:** digital transformation in medicine, formalized medical records, Data Mining, IT for assessing human state and physiological systems` state, telemedicine, m-medicine.*

INTRODUCTION

Today, Ukraine's pace of transition to high-tech industries and efficient processes is increasing using IT technologies and communications. According to the Concept of Ukraine`s Digital Economy and Society Development in 2018-2020, the key components of "digitalization" are the development of digital infrastructure — broadband Internet throughout Ukraine, and the promotion of digital transformations in various sectors of the economy and society, including medicine [1]. On the way to the digital society, it is necessary for Ukraine to combine the possibilities of domestic production with the possibility of wide use and consumption of communication and digital technologies. The experience of many world countries and the results of the implementation of products, designed by Ukrainian specialists, demonstrate the unique opportunities that digital medicine provides for increasing the efficiency of medical care.

More than 50 years ago, on the initiative of academicians V.M. Glushkov and N.M. Amosov, a new direction of scientific research — biological and medical cybernetics, was founded. During these years, scientists of the Medical Information Systems Department of the International Research and Training Center for Information Technologies and Systems have carried out research, have developed and implemented methods and means of formalization and information support for diagnostic and treatment processes.

PROBLEM STATEMENT

The modern world is rushing into the process of digital transformation (DT). First of all, this process covers the commercial activities of modern society. In their fundamental report, "Digital Transformation: A Roadmap for Organizations with Billion Turnovers", which was named as one of the top five intellectual ideas of the decade according to Whitespace/Source.com., George Westerman, Didier Bonnet, Andrew McAfee defined digital transformation for the sphere of production and management as the use of modern technologies for drastically increasing the productivity and

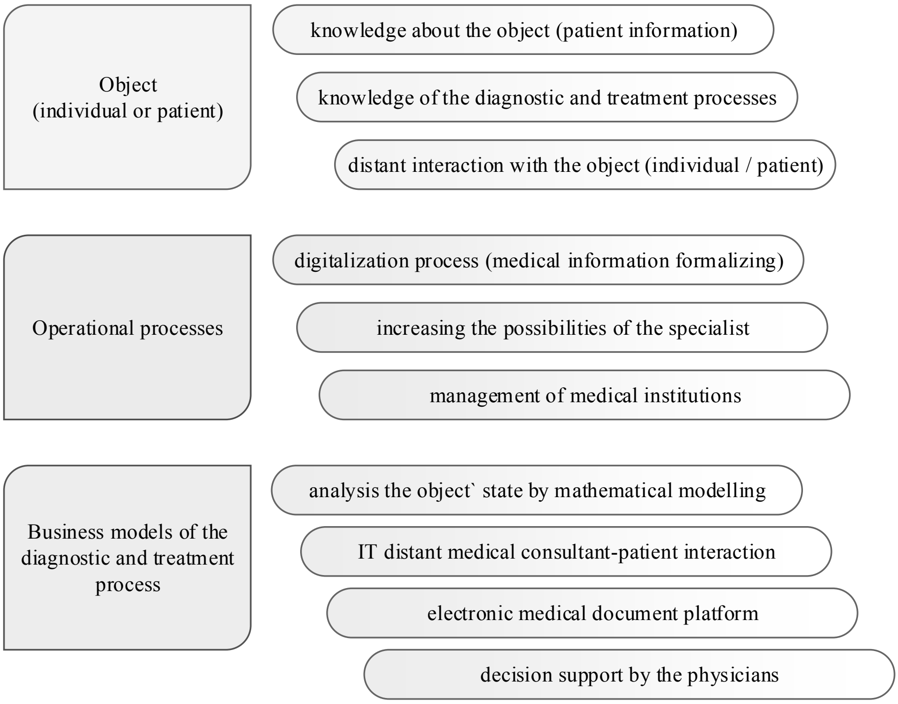

Fig. 1. Digital transformation model in medicine

value of enterprises [2]. The authors identified three key areas of enterprise activity in the digital transformation: customer experience, operational processes and business models, described the components of these areas and concluded that digital technologies combined with integrated information allow companies to obtain a global synergistic effect, while retaining the ability to react sensitively to local changes. Only some components of this model are currently implemented, the digital transformation is developing. There is a further expansion of the functions used and components of the DT.

Digital medicine (DM) as branch of digital transformation is an extremely specific area not only according to the subject, but also to the quality of the information analysed. Therefore, we define the main components of the digital transformation model (DTM) in medicine, taking into account its tasks and terminology (Fig. 1).

Digital medicine is a set of methods, technologies and technical means of computer support for the treatment and diagnostic processes, the use of which dramatically increases the efficiency of providing medical care to a specific individual/patient, as well as to the whole population or some population groups.

We have identified several main stages in digital medicine developing: I — digital transformation of primary medical information; II — development of support systems for the diagnostic and treatment processes; III — development of technologies and systems for supporting the physician`s activities with digital information; IV — mobile medicine; V — the digital medicine globalization. These stages do not have clear boundaries and can occur simultaneously when solving problems of different levels or with different degrees of preparedness of digital medicine users — medical institutions, medical workers and patients.

The purpose of the article is to analyse the stages of digital transformation in medicine and authors' contribution to the development of information technologies of digital medicine.

DIGITAL TRANSFORMATION OF PRIMARY MEDICAL INFORMATION

At this stage, digital medicine has been developing both technically and informationally. In accordance with the proposed DT model, the "Operational processes of the CM" (the digitalization of qualitative medical information, management of medical institutions) and the "Business-models of the medical processes" (Electronic medical document platform) are included.

As a part of the *technical component*, diagnostic devices giving information about the patient's health and certain physiological systems not in analogue (traditional recordings of cardiogram, encephalogram, electromyogram, etc.), but in digital form were developed.

At the same time, methods for primary processing of the received information (*information component*) were developed.

The beginning of the information component implementation was the stage of *formalization of medical information*: medical data and records, medical documents, the creation of a formalized medical history based on in-depth analysis of a patient data.

These tasks, in particular, were solved in the Medical Information Systems Department in the second half of the twentieth century. The monograph "Medical Information Systems" edited by Academician N. M. Amosov and Professor Popov A.A. that laid the foundation for the methods of formalizing medical information was first published in 1971 and republished [3]. This monograph raised a questions and gave the first decisions on the transformation of medical data presentation forms, the organization of their automated processing, the creation of formalized medical cards for some nosological groups and approaches to the development of mathematical software for medical information system.

Approaches to and methods for transforming qualitative medical information into quantitative, digital records were formed.These methods of medical data formalization became the basis for the development of standardized medical documents (health passport), as well as the creation of electronic medical records. Standardized cards for various diseases and Standardized resort card and other cards were created. Automated systems for entering, recording and storing patient`s data were developed. Today, similar methods have been applied in developing the standard for open EHR electronic medical records (Australia).

DEVELOPMENT OF SUPPORT SYSTEMS FOR THE DIAGNOSTIC AND TREATMENT PROCESSES

The beginning of this stage was laid down in the middle of the last century by few developments, now this process covers all areas of medicine, work is being carried out to create and improve DM diagnostic complexes: increasing the accuracy of analysis and diagnostics, expanding the tasks, improving usability and non-invasiveness. The development of such complexes covers a wide range of objectives, and primarily on the components of the GT model "Object" (knowledge about the object — about the patient) and "Business models of the diagnostic and therapeutic process" (using mathematical modeling methods to analyze the state of the object).

Note the enlarged groups of tasks and the results obtained by employees of MIS Department in each direction. In the 70–80 years of the twentieth century, the first in the USSR models of the course of myocardial infarction were developed based on electrocardiographic and biochemical data, which made it possible to foresee its dynamics [4]. These models were implemented into the clinical practice of the Kyiv Strazhesko Research Institute of Cardiology.

At the same time, theoretical and practical bases for the analysis of the electric field of the heart were developed using mathematical models, which made it possible to create methods for automated analysis of ECG. Software realizing the proposed algorithms was developed for the first time.

Of particular note are the problems of disaster medicine, a solution that was based on long-term (since the 70s of the last century) studies, analysis and modeling of the influence of external factors on the state of biosystems of different levels by Vasilik P.V. He created a theory of the influence of heliogeomagnetic factors on biosystems, which combines the principle of multichannel influence of solar activity on living organisms, including human, the hypothesis about the wave component of the gravitational field and the presence of a channel of non-electromagnetic nature, along with the electromagnetic channel [5]. This made it possible to predict the occurrence of epidemics, acceleration process, and climate change on Earth [6]. According to the results of the analysis of accident data on various public infrastructure objects, periodograms of time series were calculated and it was determined that there are rhythms in land and air transport accidents, which will reduce the probability of emergency situations and, consequently, the level of injuries [7].

Studies of changes in the state of an individuals and several physiological systems using methods of mathematical modeling were carried out and their results have formed the basis of decision support information technology in the field of preventive medicine. Developed IT for assessing the psychophysiological state of students to support the activities of psychologists in middle and high schools [8–9], functional state models of the operators with high visual strain to identify asthenopic disorders [10–11], IT for assessing of the population medical and demographic state under the influence of various factors, which serve as the basis for the formation of information support for management decision-making in the health care system [12–15].

In recent years, we have developed the **method for determining markers of the cardiovascular system functional state**, which is based on mathematical models of communication of the ECG signs [16] and comprehensive assessments of the regulation, state and reserves of the myocardium.

For prenosological diagnostics, it is important to carry out a comprehensive assessment of the functional state (FS) of the cardiovascular system (CVS), based both on the study of heart rate variability (HRV) [17] and on in-depth analysis of 6, 12-channel ECG recordings [18].

A large amount of the initial data set (more than 300 ECG signs) and the need for standardization of indicators into the interval deviation scale necessitated the development of a multivariate method for analysis the functional state of the CVS using Data Mining methods (DM). The peculiarity of medical data is a large number of various interrelated parameters, often for small groups of observations. Data Mining methods are more efficient for the selection of informative features, since, unlike the statistical ones, there are no prerequisites for the data. Data processing methods allow us to build a large number of prognostic models for both large and small groups of observations. This allows us to obtain in an accessible form a new knowledge that may be introduced into clinical practice.

The method combines the following stages.

Stage I. Data preparation. The objectives of this phase are:

• primary processing, which covers the cleaning, transformation, identification of missing data, recoding;

• standardizing of primary indicators using an interval scale;

• defining target (dependent) variables and a set of independent indicators;

• dividing data into training and examination, testing samples in the case of large samples (databases).

Stage II. Clustering Data. Segmentation includes the following steps.

2.1. The division of the sample of patients into typological groups is carried out according to complex indicators (vegetative regulation state, estimates of the myocardium and its reserves) and/or disease severity. To distribute patients into groups, the *k*-Means method is used, which is implemented in the DM module. This method makes it possible to calculate the optimal division into groups according to the following criteria:

- Criterion for calculating cluster centres with minimization of the target function:

$$F_1 = \sum_{n=1}^{k} \sum_{x_i \in X_n} \|\mu_i - \mu_n\|^2 \to \min,$$

where n is the number of objects to be divided into k-groups (clusters), F_1 is the sum of squares of distances between each object x_i and the centre of the cluster μ_n to which it belonged at each iteration;

- Criterion of the largest sum of distances between clusters:

$$F_2 = \sum_{n,i=1}^{k} \|\mu_i - \mu_n\|^2 \to \max.$$

2.2. In contrast to the classical *k*-Means method, in this method we additionally included a cross-check for *n* random samples, which allows minimizing the error and choosing the optimal number of clusters. Optimization is carried out before solving for clusters *k*+1, at which the error function (average distance to cluster centres) is not more than 5% better compared with the solution of clusters *k*. Then the solution with *k* clusters will be optimal and final.

2.3. Standardization of variables is carried out to convert it to the range from 0 to 1:

$$z_i = \frac{x_i - x_{\max}}{x_{\max} - x_{\min}}.$$

The distance between objects and cluster centres is calculated using the Euclidean distance.

The results of this stage make it possible to identify and analyse the typological features of the selected clusters, taking into account such indicators as evaluation of the CVS regulation, myocardial state (level of adaptation) and others for the subsequent determination of predictors (the most informative signs) on the basis of which violations of the regulation of cardiovascular system and of myocardium state can be forecasted.

Stage III. Building models. This stage is aimed at identifying predictors and combines several steps.

3.1. Feature Selection:

• identifying important predictors from a variety of prognostic features;

• removing unnecessary predictors.

3.2. Building models (forecast and classification) may be carried out using several approaches: Neural Networks, Method of Classification and Regression Trees, Boosted Trees.

3.3. Evaluation and comparison of simulation results to determine the optimal model (for performance and complexity).

In this investigation, we use the Method of Classification and Regression Trees (C & RT). The method of decision trees is a hierarchical and flexible means of predicting the belonging of objects to a certain class or predicting the values of quantitative variables. This method allows us to get a model, which is a set of rules "IF (A) THEN (B)", where A is a logical condition, B is a subdivision procedure a subset into two parts, for one of which condition A is true, and for the other, it is wrong. The results are easy to interpret because the rules are presented in the form of a graphic structure (tree).

The construction of the tree goes from top to bottom by applying a recursive procedure to a training sample (size N) using the following algorithm.

Selecting the threshold value of the variable $x = A$ will provide “optimal partitioning” according to a certain criterion for the target variable y.

For regression trees, the function of estimating the quality of a partition is the sum of squared deviations or the mean square error:

$$MSE = \frac{1}{N}\sum_{1}^{N}(y_i - \hat{y})^2 .$$

For classification trees (target variable is categorical), the Gini index or the statistical criterion $\chi 2$ can be chosen as such a criterion:

$$Gini(d) = 1 - \sum_{i \neq j}^{k} p_i^d \ p_j^d ,$$

where p_i is the classification probability at node d as i or j, *Gini (d)* is the degree of uncertainty reduction at node d.

Separation of data into subsets is applied for each subset (internal node).

Thus, the algorithm for constructing decision trees allows us to define a set of characteristic values (attributes) that separate one data category from another. This process is called segmentation.

The depth of the tree (its size) depends on the amount of data. The more branches a tree has, the better results of its testing on a training sample will be, but less successful they will be on an examination sample. Therefore, the constructed model should also be optimal in size, that is, it should contain information that improves the quality of recognition, and should ignore the information that does not improve it. To do this, tree pruning is done.

A peculiarity of the C & RT algorithm is the choice of the optimal tree size using cross-validation.

Stage IV. Verification of the classification model.

At this stage, the selected model with the optimal set of predictors is compared with the previously obtained division into typological groups (clusters of the II stage) or with the patient's state (severity of the disease). The confusion matrix is calculated on typological groups obtained at the II and III stages.

Thus, the proposed method allows the construction of predictive and classification models of the relationship of complex indicators of the cardiac activity regulation, assessments of the myocardium state and its reserves with ECG indicators, the analysis of these models makes it possible to study the peculiarites of the cardiac activity regulation.

The method was used to analyze the functional state of the CVS of children with rheumatic diseases according to the signs system of a 6-channel ECG. The results of the clinical and instrumental examination of children (41 children with rheumatic diseases) who were hospitalized at the Institute of Pediatrics, Obstetrics and Gynecology of the Academy of Medical Sciences of Ukraine were the basis for developing models of the relationship of the studied parameters according to the proposed method. ECGs were recorded and analyzed using the “Cardio Plus P” software and hardware complex with the Cardio ORAKUL software. The “Cardio-plus P” registers a large number of amplitude-time parameters, frequency indicators, characteristics of the in-depth analysis of the ECG, and with the help of computer programs it calculates a multi-level system of ECG estimates. The analysis is carried out according to the hierarchical system of ECG assessments proposed in [18]. The system under study identifyes four blocks of indicators.

Block of heart rate variability (HRV). HRV indices reflect the work of the cardiovascular system and the mechanisms of regulation of the whole organism. The HRV method is widely used in functional diagnostics, mass prenosological surveys, for rapid diagnosis. These are indicators of temporal, spectral, geometric analysis, as well as measures of nonlinear analysis of the heart rhythm complex dynamics. On their basis, two secondary indicators are formed — operational control of regulation and the state of regulation reserves, the third generalizing indicator — a comprehensive regulation assessment, is formed from them [16, 18].

The block of amplitude-time ECG indicators has more than 130 signs. It is known that a complex of ECG amplitude-time indicators may be the markers of the risk of adverse cardiovascular events (sudden death, myocardial infarction, heart failure). This complex characterizes the regulation of the heart (operative control of the myocardium state and reserves), and the degree of compliance of these indicators with the norm is a measure of the functional reserve.

Based on the primary features of these two blocks, comprehensive assessments of the HRV regulation, myocardial conditions and indicators of in-depth ECG analysis are formed.

The following blocks combine ECG signs of cardiac arrhythmias and psychoemotional indices. The final assessment is an integral indicator of the FS of the CVS. It is formed as a linear convolution of complex indicators and other ECG signs.

The algorithm for calculating the complex indicators system as a method of electrocardiogram universal score evaluation was proposed and described in detail in [20]. According to the specified system of indicators, forecast and classification models were constructed. The model in the form of a decision tree clearly represents the rules for classifying observations, and the regression tree shows the dependence of the target variable on the predictors. Each classifying rule reflects a certain regularity that is hidden in empirical data.

Let us give a solution to one of the research problems. Figure 2 shows the regression tree calculated by the C & RT algorithm for a complex indicator (assessment) of the myocardium state. This tree obtained by cross-validation (10-fold cross-validation), is optimal both in size and in the number of predictors. Teaching data set — 41 children. The predictors are 5 signs:

1) the integral indicator of the form STT (lead II) integral form indicator STT (lead II);

2) ECG wave amplitude index (lead AvF) ECG wave amplitude index (V AvF));

3) T wave amplitude (lead II);

4) ST segment offset 0.08 sec after point J (lead II) ST-segment depression at 80 ms after the J-point (V II)

5) angle αT in the frontal plane (lead II).

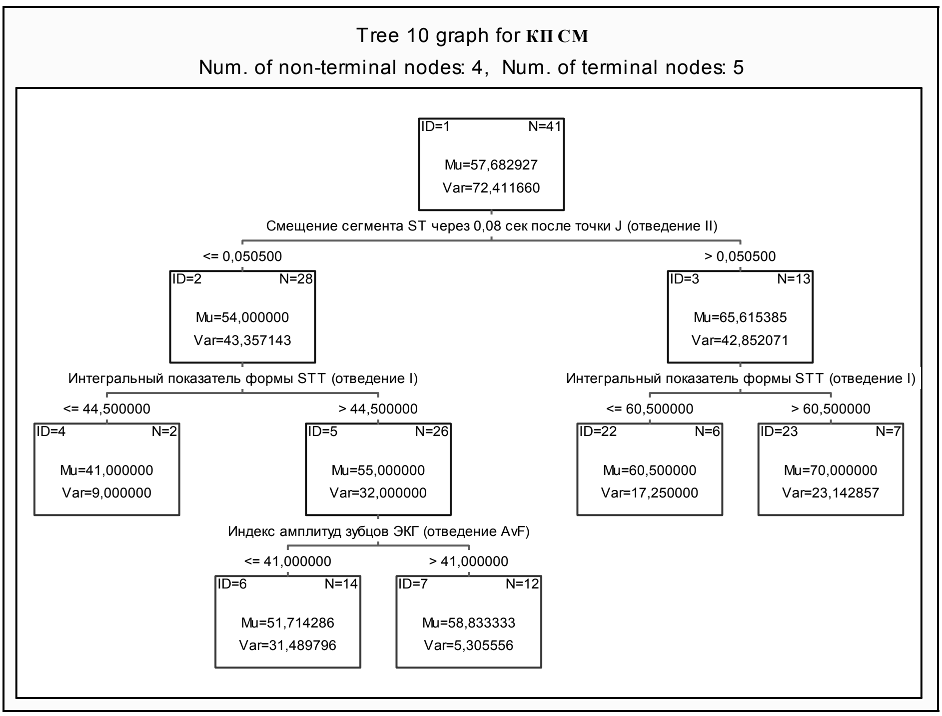

Fig. 2. Regression tree for a complex indicator (assessment) of the tate of the myocardium

The root node indicates the average value of the complex indicator of the myocardium state (CIMS) of a group of children with rheumatic diseases (CIMS = 57.6%). The value of the indicator "ST segment displacement after 0.08 s after point J" equal to 0.05 mV determines the division into two main groups (with low and higher myocardial scores).

The method allows to indicate the ECG predictors of the cardiovascular system functional state according to estimates of vegetative regulation, the state of the myocardium and its reserves, to determine the boundary values of these predictors for different groups of patients, as well as to identify different functional classes.

DEVELOPMENT OF INFORMATION TECHNOLOGIES AND SYSTEMS TO SUPPORT THE PHYSICIAN`S ACTIVITIES WITH DIGITAL MEDICAL DATA

The development of this stage corresponds to the components of the DTM model — "Object: patient" (knowledge of the treatment and diagnostic process) and "Operational processes" (increasing the possibilities of a specialist; managing the medical institutions activities).

1. The level of medical institutions

Over the past 30 years, a large number of complex medical systems (CMS) have been developed. The implementation effectiveness of these CMS depends on their compliance with the real needs of the medical institution, so CMS functional content must be analyzed at the pre-project stage [19]. Recently the main efforts have been made to ensure the effective information exchange between different systems and modules. It is the reliability of this exchange that will enable the physician to use the necessary set of various digital medical data for the diagnosis and treatment of patients.

Digital medical data includes, in addition to clinical and laboratory data, such large groups as digital medical signals and digital medical images (DMI). A large amount of unique medical information comes to the physician in the medical images form. It should be emphasized that such information will be sufficient for analysis only if there is metadata that links the images with complete patient data, time and means of obtaining these images. The necessary conditions for the diagnostic process are the unification of medical data, convenient storage and data losless transmission both across the hospital's local network and between different medical institutions using the standard for regulating the creation, storage, transmission and visualization of medical images and documents — Digital Imaging and Communications in Medicine (DICOM) [20].

Solving various problems of information support of providing medical care to patients of the Hospital for Scientists of the National Academy of Sciences of Ukraine has been the subject of our research and development for more than 20 years. A Hospital information network combining a medical information system (MIS), diagnostic digital devices of various modalities with a DICOM prefix and a medical image storage module has been developed. To ensure the interaction of old-style equipment (without using the DICOM standard), a module has been developed for the transmission and conversion to digital medical images, which allows communication with the Conquest DICOM Server and supporting the necessary functions of operating with data and digital medical images.

The main task of the *developed information technology for supporting the processes of receiving, transmitting and storing digital medical information* is to ensure effective work of the physicians with digital information from various sources: diagnostics complexes, digital medical data and image storage using Picture Archiving and Communication Systems (PACS) and cloud technologies. The use of this technology provides the organization of long-term storage of digital medical images obtained from diagnostic systems, and the ability to use this medical information by the physician at his workplace in the current treatment and diagnostic process [21, 22].

2. Telemedicine — interregional level

The theory of telemedicine (TM) systems developed by us includes the formulated principles of TM systems organization (principles of hierarchy, adaptability, fractality and scaling), criteria and methods for analyzing digital medical data [23, 24].

The principle of hierarchical construction of the TM network allows to coordinate its structure with the organization of the health care system, in the information environment of which the TM network functions. The principle of adaptability provides the opportunity to develop the network using new technological platforms to expand the target space and increase the efficiency of medical care by upgrading the information and communication basis of TM technologies. The principle of fractality provides a "vertical" similarity to different levels of the structure of the MT network and determines the flexible process of preparing and exchanging medical data by implementing the similarity function. According to the principle of scaling, the "horizontal" organization of the MT network is carried out, ensuring the possibility of replication of software products at the regional level and at the level of individual medical institutions.

There are several levels of telemedicine institutions that are interconnected technically, informationally and documentally. The first level of the TM network includes telemedicine centres or nodes located in different districts and regions of the country (*Counseling Objects*). *Counseling Subjects* are medical institutions that provide consulting services and have a staff of highly qualified medical specialists in various fields of medicine, as well as appropriate equipment for remote consultations, medical diagnostic procedures and organization of training for network users. This is the second level of the MT network and organization can be both objects and subjects of counseling. At the third level, there is the Telemedicine Center of the Ministry of Health of Ukraine, which includes a dispatch center and also carries out scientific and methodological activities.

The introduction of this IT into the work of the Telemedicine Center of the Ministry of Health of Ukraine enabled to provide the population of more than 20 regions of Ukraine with qualified medical assistance.

3. Harmonization of medical informatics standards

To integrate MISs into a single network and to enter the international information space, it is necessary to ensure the standardization of information carriers and the transmission of medical images. On the basis of international standards Health Level 7 and DICOM, we harmonized standards in the field of medical statistics and health informatics. Harmonized standards are focused on defining data types for information exchange, defining requirements for the general structure of biometric data exchange formats, presenting units of measure for data exchange between computer applications, requirements for drugs dictionary systems for healthcare and to electronic prescriptions. Such standards are essential for the development of mobile medicine.

MOBILE MEDICINE

At the present stage, the development of mobile intelligent information technologies (IIT) for digital medicine is underway. The basic structure of any mobile application consists of a kernel (platform based on Android, IOS or Windows Mobile) and functional blocks that are formed taking into account the specific tasks of this mobile application for a specific group of users (Fig. 3) [25]. When developing medical mobile applications, we focus on two main types of users — the physician and the patient. They differ one from other intheirs possibabilities and restrictions on access to certain information. Applications can be used in full or partial mode.

Methods and means of IIT based on the use of mobile devices provide increased efficiency of medical care to the population by preventing chronic disease, increasing the duration of remission, reducing the recurrence of the disease. When using such IT for medical care to patients, there is also a decrease in the cost of treating and rehabilitating patients, increasing the efficiency of storing and transmitting medical data with accelerating the exchange of digital medical information.

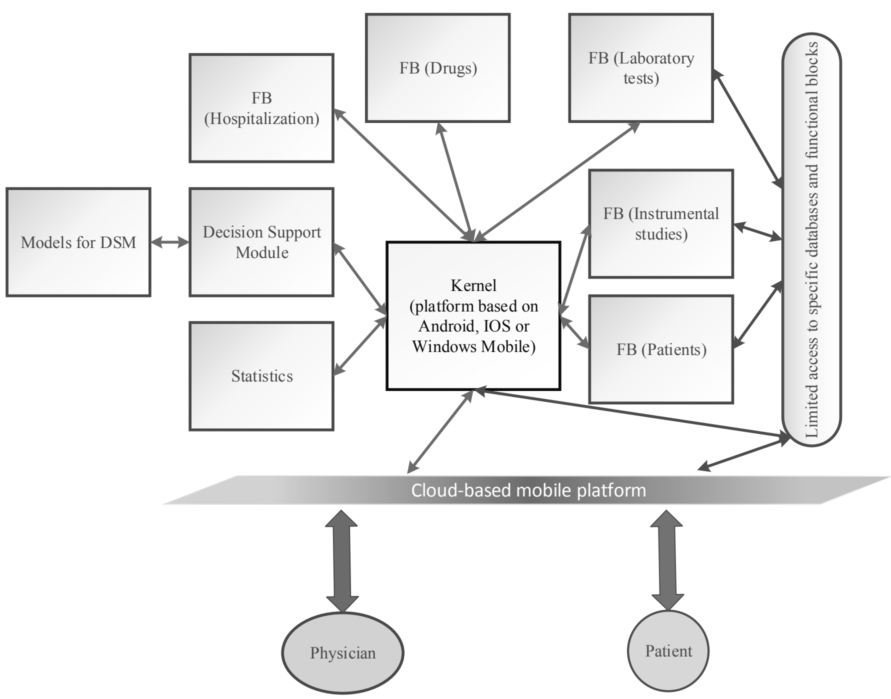

Fig. 3. Interconnection of mobile applications targeting a physician and patient

THE DIGITAL MEDICINE GLOBALIZATION

This is the stage of the future development of digital interstate medicine. Telemedicine and the use of mobile applications are only two facets of this process. It is necessary to create global knowledge bases that include detailed information not only about standard pathological cases, but also about deviations in the course of pathological processes and the corresponding medical means, about risk groups etc. As any interstate process, globalization of digital medicine requires serious analysis and development of legal foundations taking into account the principles of insurance medicine in different countries.

But we should not forget the ambiguous moments of the DM spread. The indisputable relevance and significance of DM induces a proposals flurry from the fields of engineering and technology, much of which are “quickly baked”, not based on the principles of evidence-based medicine, and on a rigorous analysis of the preliminary studies results. There are cases of development of automated decision support systems by physicians, in which the physician is practically excluded from the technological chain. One of the mostly developing areas of DM is the creation of a variety of sensors to collect information about the patient's state. But only a part of these proposals was accepted by physicians for practical use.

Thus, the digital transformation in medicine, like any new process, undergoes the stages of gradual complication of tasks, methods and means for their implementation: from formalization of primary medical information to improving methods for its analysis, transmission and storage to improve the quality of medical care for patients any time and at any point of the world.

CONCLUSION

The developed model of digital transformation in medicine includes such components: Object, Operational processes and Business models of the treatment and diagnostic processes, for which functions and tasks are selected taking into account the specifics of the subject area according to object and quality of the analyzed information.

There are several main stages in the digital medicine development: I — digital transformation of primary medical information; II — development of support systems for the diagnostic and treatment process; III — development of technologies and systems for supporting the physician’s activities with digital information; IV — mobile medicine; V — the digital medicine globalization. The beginning of the digital transformation of primary medical information laid the formation of methodological foundations for the creation of formalized medical records and standardized documents.

The proposed method for determining markers of functional status of the CVS, based on mathematical models of forecasting and classification using Data Mining, allows to determine the boundary values of these predictors by the identified ECG predictors of the CVS functional status (estimated vegetative regulation, myocardial state and its reserves) for different groups of patients, as well as to define different functional classes.

The development at the stage of IT support for a physician’s activity with digital medical data ensures the implementation of such functions of digital transformation model in medicine: the acquisition of knowledge of the diagnostic and treatment processes, enhancement of the specialist's possibilities, management of medical institutions. These functions are carried out both at the level of a medical institution and at the interregional level using international standards of presentation and transmission digital medical data.

The basic structure of any mobile application consists of a kernel (platform based on Android, IOS or Windows Mobile) and functional blocks that are formed taking into account the specific tasks of this mobile application. The development of medical mobile applications is focused on at least two main types of users — the physician and the patient, mobile applications for them are distinguished by a set of opportunities and restrictions on access to certain information.

Medicine is already faced with the squall of information, which is being formed through the use of new IT sources: large functional diagnostics complexes, digital clinical laboratories, mobile data sensors of patients' health in real time regime and others. This necessitates the creation of large information networks using cloud technologies for storing information and intelligent information technologies to provide the necessary level for analysing this huge amount of information and supporting decision-making by the physicians at all the stages of the diagnostic and treatment processes.

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ЦИФРОВА ТРАНСФОРМАЦІЯ В МЕДИЦИНІ: ВІД ФОРМАЛІЗОВАНИХ МЕДИЧНИХ ДОКУМЕНТІВ ДО ІНФОРМАЦІЙНИХ ТЕХНОЛОГІЙ ЦИФРОВОЇ МЕДИЦИНИ

Вступ. Відповідно до Концепції розвитку цифрової економіки і суспільства України на 2018-2020, прийнятої у січні 2018 року, серед ключових складників «цифровізації» є розвиток цифрової інфраструктури — широкосмуговий Інтернет по всій території України, і стимулювання цифрових перетворень у різних галузях економіки і суспільства, зокрема у медицині.

Метою статті є аналіз етапів цифрової трансформації в медицині і розробок авторів і їхніх колег відділу медичних інформаційних систем з розвитку інформаційних технологій цифрової медицини.

Результати. Надано сформовану модель цифрової трансформації в медицині та виділено декілька основних етапів розвитку цифрової медицини: I — цифрова трансформація первинної медичної інформації; II — розроблення систем підтримки лікувально-діагностичного процесу; III — розроблення технологій і систем підтримки діяльності лікаря з цифровою інформацією; IV — мобільна медицина; V — глобалізація цифрової медицини.

Запропоновано метод визначення маркерів функціонального стану серцево-судинної системи, в основу якого покладено математичні моделі прогнозу та класифікації із застосуванням Data Mining, що дає змогу виявляти та визначати граничні значення ЕКГ предикторів функціонального стану серцево-судинної системи для різних груп пацієнтів. Відзначено інформаційну технологію підтримки процесів отримання, передачі та зберігання цифрових медичних зображень, яку спрямовано на забезпечення ефективної роботи лікаря з цифровою інформацією з різних джерел: комплекси функціональної діагностики, сховища цифрових медичних даних і зображень з використанням PACS і хмарних технологій. Застосування в роботі Центру телемедицини запропонованої теорії телемедичних систем, яка включає сформульовані принципи організації цих систем, критерії та методи аналізу цифрових медичних даних, дало можливість охопити кваліфікованою медичною допомогою населення більше 20-ти областей України.

Висновки. Розвиток цифрової трансформації у медицині проходить стадії з поступовим ускладненням завдань, методів і засобів їх реалізації: від формалізації первинної медичної інформації до удосконалення методів її аналізу, передачі і зберігання для підвищення якості медичної допомоги пацієнтам в будь-який час та у будь-якій точці країн світу.

Ключові слова: *цифрова трансформація у медицині, формалізовані медичні записи, інформаційні технології оцінювання стану людини та фізіологічних систем організму, телемедицина, мобільні застосунки.*

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ЦИФРОВАЯ ТРАНСФОРМАЦИЯ В МЕДИЦИНЕ: ОТ ФОРМАЛИЗОВАННЫХ МЕДИЦИНСКИХ ДОКУМЕНТОВ К ИНФОРМАЦИОННЫМ ТЕХНОЛОГИЯМ ЦИФРОВОЙ МЕДИЦИНЫ

Проанализированы этапы цифровой трансформации в медицине: I — цифровая трансформация первичной медицинской информации; II — разработка систем поддержки лечебно-диагностического процесса; III — разработка технологий и систем поддержки деятельности врача с цифровой информацией; IV — мобильная медицина; V — глобализация цифровой медицины. Показан вклад разработок авторов и их коллег (отдел медицинских информационных систем) по развитию информационных технологий цифровой медицины на этих этапах**.** Представлены разработанные: метод определения маркеров функционального состояния ССС; ИТ поддержки процессов получения, передачи и хранения цифровых медицинских изображений; теория телемедицинских систем и результаты ее применения; базовая структура мобильного медицинского приложения и взаимодействие ее функциональных блоков с выделением задач и ограничений действий основных пользователей — врача и пациента.

Ключевые слова: *цифровая трансформация в медицине, формализованные медицинские записи, Data Mining, информационные технологии оценки состояния человека и физиологических систем организма, телемедицина, мобильные приложения.*