REVIEW ARTICLE

Prerequisites for implementing expert medical modeling based on human digital physiology programs

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ABSTRACT

Aim: To explore the components, approaches, and principles of expert medical modeling utilizing modern digital medical imaging and human digital physiology programs.

Materials and Methods: The research methodology involves an analysis of current regulatory documentation, including acts of the Cabinet of Ministers of Ukraine related to healthcare digitalization. It also incorporates scientific and analytical sources on medical informatics, digital medical simulation, and data visualization standardization. Comparative analysis methods were applied to medical imaging standards, along with content analysis of medical literature and an evaluation of the potential for expert assessment of the human condition using immersive technologies.

Conclusions: The study emphasizes the need to integrate digital media across all levels of healthcare to develop a unified expert information visualization system based on human digital physiology programs. This approach enables objective decision-making and supports the development of personalized models using 3D/4D imaging and artificial intelligence.

KEY WORDS: expert medical modeling, medical imaging standard

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INTRODUCTION

Digital transformation in healthcare is a key element in modernizing clinical practice [1, 2], diagnostics, and rehabilitation. One of the leading directions is the implementation of digital medical visualization standards, which ensure the storage, processing, and exchange of visual medical data [3]. Within the framework of national digital development strategies–particularly in the context of implementing the Concept for the Development of Digital Competencies and the Electronic Healthcare System in Ukraine–the integration of digital visualization technologies is of strategic importance [4].

For the implementation of expert medical modeling, it is necessary to define the essential conditions for the circulation of digital medical content within specialized and expert networks.

First and foremost, all medical–especially expert–personal models and conclusions must be entered under blockchain conditions, a decentralized network [5] that operates on the principle of a sequential chain of blocks containing information about operations with tokens, a unit of account in the blockchain network through which digital values can be created. Records in the blockchain are immutable and publicly accessible, thereby preventing data manipulation and ensuring their security [6, 7].

Compliance with this condition will ensure the use of non-fungible tokens (NFTs)–a type of digital asset created on the blockchain that allows ownership of a unique item in the network, such as an image, animation, or video, while verifying its authenticity [8].

AIM

The aim of this study is to explore the components, approaches, and principles of expert medical modeling (EMM) using modern digital medical visualization tools and computer-based human digital physiology programs.

MATERIALS AND METHODS

The methodological basis of the study is the analysis of current regulatory and legal documentation, including acts of the Cabinet of Ministers of Ukraine regarding the digitalization of the healthcare sector, as well as scientific and analytical sources on medical informatics, digital medical simulation, and data standardization of visualization systems. Methods included comparative analysis of medical visualization standards and content analysis of medical literature addressing the possibilities of conducting expert assessments of the human body's condition.

The data analysis was conducted using open sources, predominantly covering the period 2010–2025. Some earlier sources were included to trace retrospective trends and sustainability. The main search keywords were "standards of medical imaging", "digital examination methods", "virtual technologies in medicine", and "application of artificial intelligence in medicine". The search criteria focused on contemporary approaches and practical experience in the use of digital technologies, particularly in simulation medicine. Sources primarily aimed at transforming objective digital media into subjective forms–by generating textual conclusions or reports–were excluded from consideration. The initial database comprised approximately 70 sources, of which 35 were included in the final analysis.

ETHICS

This review article is based on an analysis of publicly available scientific data published in peer-reviewed journals, clinical guidelines and databases. No patient-identifying data was used during the work, nor was there a need to obtain approval from an ethics committee, as the study did not include new clinical interventions or initial collection of patient information.

The authors adhered to the ethical principles of the Helsinki Declaration of the World Medical Association and international standards for publications in medical journals, including the recommendations of the ICMJE (International Committee of Medical Journal Editors).

No element of the work contains plagiarism or data fabrication. All sources of information are appropriately cited and properly formatted.

REVIEW AND DISCUSSION

During the study, the authors formulated a definition of the term "expert medical modeling" (EMM) as follows: EMM is the creation of a digital model of the human body based on a computer program of digital physiology for conducting a comprehensive expert assessment of the possibility of performing a proposed functional load and for further prognosis of its condition [9, 10].

Historically, the modeling of the human body–apart from works of science fiction–has been used in medicine for quite some time [11, 12]. The introduction of the term "virtual twin" into the medical lexicon in modern Ukraine dates back to 1971, when it was primarily used by pharmaceutical companies. The term "avatar" has gained wider use. In the context of computer technology, it can be traced back to Neal Town Stephenson's novel Snow Crash (1992). The INACSL (International Nursing Association of Clinical Simulation and Learning) Standards Committee defines an avatar as "a graphical representation, usually three-dimensional, of a person, capable of reproducing relatively complex actions, including facial expressions and physical reactions during participation in virtual simulation training" [12].

Conditionally, such programs were mainly educational or clinical in nature [13, 14]. The most well-known programs and developments include Stanford Virtual Reality Integration, particularly Stanford Virtual Heart and Surgical Theater; Oxford Medical Simulation; SimX; and the AI BODY digital physiology program, among others. Considerable progress has been achieved in the creation of 3D models based on digital media obtained from computed tomography (CT) or magnetic resonance imaging (MRI) scans, with subsequent reconstruction of lost anatomical connections of the body through 3D printing [15, 16]. This direction has developed most actively in prosthetics and reconstructive surgery, particularly in response to the large number of casualties from combat operations.

At the same time, for stable functioning and realistic reproduction of visual effects, these programs rely on digital media generated using medical visualization tools [17, 18]. Medical visualization refers to the methods and processes used to create images of different parts of the human body for diagnostic and therapeutic purposes within digital medicine [1, 2, 4].

The use of medical visualization enables physicians to obtain more accurate diagnoses and make corresponding treatment decisions. Visualization standards and file formats play a significant role in the annotation of medical images. Standardization applies not only to the processes of archiving digital files but also to ensuring access to them and facilitating exchange between structural units of the medical and preventive care network [19, 20].

The main universally recognized standards in the field of digital medical visualization include:

- DICOM (Digital Imaging and Communications in Medicine) - provides a universal format for the exchange and archiving of medical images, supported by most modern diagnostic equipment [21];
- NIfTI (Neuroimaging Informatics Technology Initiative) - solves problems in the field of neurovisualization,

Table 1. Comparative Implementation of DICOM and NifTI Formats in Clinic and Research

Format	Geography of implementation	Industry	Example of use
DICOM [24]	USA, UK, Japan	Clinical Medicine	PACS Archives, telemedicine, AI diagnostics at Mayo Clinic
NIfTI [25]	USA, EU, Canada, Australia	Neuroscience	Human Connectome Project, depression analysis, functional MRI modeling

Source: compiled by the authors based on [24, 25]

Table 2. Comparative Analysis of DICOM and NIfTI Applications

Criterion	DICOM [24]	NIfTI [25]
Format	2D image with metadata	3D/4D Arrays
Appointment	Clinical practice	Neuroresearch
Image orientation	Partially supported	Spatially and temporally determined
Processing speed	Low	High
Amount of metadata	High	Surveys

Source: compiled by the authors based on [24, 25]

with an emphasis on functional magnetic resonance imaging [22, 23].

Since the study involves working with digital data of the human body under blockchain conditions, it is worth mentioning the standards and protocols of confidentiality of personalized information, namely:

- PACS (Picture Archiving and Communication System) - a system for storing and accessing images;
- HL7 (Health Level Seven) - a standard for the exchange of clinical and administrative information between medical systems;
- FHIR (Fast Healthcare Interoperability Resources) - a modern standard for the exchange of electronic medical information. FHIR is based on open web standards and provides a more flexible and easier exchange of data between different electronic medical documentation systems;
- TLS (Transport Layer Security) and HTTPS (Hypertext Transfer Protocol Secure) - protocols that provide encryption of data during its transmission over the Internet, ensuring the confidentiality of patient data;
- VPN (Virtual Private Network) - provides a secure tunnel for transmitting data between network nodes, allowing to protect data from unauthorized access during their transmission over unprotected networks, such as the Internet [23].

For a more gradual movement, it is advisable to briefly review the history of creation and directions of use of the two aforementioned main standards of digital medical visualization, namely DICOM [24] and NIfTI [25].

DICOM format was developed in the 1980s by the American College of Radiology (ACR) in collaboration with the National Electrical Manufacturers Association (NEMA) in the USA. The first DICOM 1.0 specification was released in 1985 under the name ACR/NEMA 300 [24].

Over time, the format became an international standard (ISO 12052) and was adapted in over 150 countries. Universities, hospitals, and research centers around the world use it in daily clinical practice:

In the USA, DICOM is a standard in all institutions accredited by the Joint Commission; large networks (Mayo Clinic, Cleveland Clinic) have integrated PACS systems based on DICOM [24]:

- In Great Britain, the NHS (National Health Service) has fully transitioned to DICOM images under the "National PACS Programme" back in 2008 [24];
- In Japan, over 90% of hospitals use DICOM-compatible systems, including in telemedicine consultations in rural areas;
- In Germany and France, DICOM is part of national medical informatics standards, supported by legislation on electronic medical documentation (eHealth). Hospitals around the world use DICOM not only because it allows exchanging images and annotations but also because of the simplicity of transmission, providing references to patient medical records and other valuable metadata [24].

NIfTI format was developed in 2001-2003 under the auspices of the National Institute of Mental Health (NIMH) for the needs of neuroscientific research, particularly functional MRI [10]. Its main advantage is the compact storage of large arrays of 3D/4D data, with spatial and temporal orientation [25].

It has become the primary format used in the Human Connectome Project (USA), UK Biobank (United Kingdom), and the ENIGMA Consortium–a global neuroscience initiative encompassing more than 40 countries. NIfTI is widely applied in scientific and medical computations (HPC/AI), including in software packages such as SPM (Statistical Parametric Mapping), FSL (FMRIB Software Library), and AFNI (Analysis of Functional NeuroImages), which are considered de facto standards for functional MRI analysis. It is also supported within the European Union as the primary format in Horizon Europe projects focused on brain research and neuropsychiatric disorders [25].

For a clearer visual representation of the global distribution of medical visualization standards and the predominant directions of their scientific and practical use, all the aforementioned characteristics of these standards are summarized in Table 1 [24, 25].

The conditions of technological application in various fields of medical practice, and peculiarities of work with different standards of medical visualization are grouped and presented in Table 2 [24, 25].

The concept of expert medical modeling (EMM) has evolved through several technological and methodological stages – from the early era of telemedicine, focused on remote consultations and data transfer, to the modern paradigm of the digital twin, which enables full-scale virtual replication of human physiology. Telemedicine primarily addressed the accessibility of healthcare and real-time communication between physicians and patients. The next stage emerged with the advancement of medical visualization technologies such as computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET), which allowed precise digital reconstruction of anatomical structures. The development of interoperability standards further enabled the integration of heterogeneous medical data into unified expert systems [24, 25].

Today, EMM represents a synthesis of medical informatics, big data analytics, and bioethics, forming the foundation for the creation of dynamic, data-driven digital replicas of patients – virtual clinical twins – to support diagnostic, rehabilitative, and prognostic decision-making. This transition from telemedicine to digital twin–based modeling reflects the global shift from reactive to predictive and personalized medicine, where expert judgment is grounded not only in professional experience but also in objective digital evidence [26].

Digital visualization is changing the paradigm of long-term expert clinical observation. The transition from subjective interpretations to objective digital models creates new challenges and requirements for the digital literacy of medical professionals and the overall organization of medical care. In particular, the implementation of EMM poses a specific algorithm of actions:

- obtaining a digital medium based on a specific standard of medical visualization;
- saving the digital medium based on a specific standard of medical visualization;
- integrating the specified digital data into the research program of expert modeling;
- creating a current expert model of the organism of the study subject;
- conducting virtual load tests and generalizing and saving their results;
- forming a preliminary expert conclusion with reference to the virtual file of the current virtual research model;
- further forming expert models based on fresh digital media to track trends in the development of improvements/complications in the human body over time [26-30].

This shift towards digital models necessitates a re-evaluation of training programs for medical professionals, emphasizing digital literacy and the interpretation of complex datasets. Furthermore, the implementation of expert medical modeling (EMM) requires careful consideration of data security and patient privacy, particularly when using blockchain technology [8]. As Y. Ghadi et al. [9] note, the role of blockchain in securing the Internet of Medical Things (IoMT) is crucial; however, challenges related to scalability and regulatory compliance remain to be addressed.

The virtual visualized object, formed with all its anatomical, physiological, clinical, psychological, and functional characteristics, and presented in accordance with the International Classification of Diseases (ICD) and the International Classification of Functioning, Disability, and Health (ICF), can be subjected to virtual loading tests to determine the organism's tolerance to various levels of functional stress. The virtual conclusions obtained as a result of executing the expert chain should serve as the basis for decisions regarding the level of disability, recommendations for further treatment and rehabilitation methods, and guidance on future employment [2, 4, 12].

This is particularly relevant in Ukraine today, against the backdrop of the large number of casualties resulting from combat operations. The number of people requiring rehabilitation after emergencies and specialized medical care continues to increase almost daily. The consequences of traumatic factors of various origins have led to a significant number of individuals who have partially or completely lost the ability to perform their previous professional duties. This situation hampers medical and social adaptation, affects the psycho-emotional state of injured persons, and generates negative expectations regarding their own future prospects. As a result, many demobilized individuals suffer from so-called "military syndromes", which pose significant obstacles to their full reintegration into civilian life. Further research is needed to explore the long-term impact of these syndromes and to assess the effectiveness of EMM in facilitating rehabilitation [31, 32].

In addition, numerous scandals concerning the subjectivity of conclusions reached by medical-social and military-medical expert commissions have further undermined public confidence. The introduction of the proposed EMM, based on a computer program of digital physiology, would make it possible to achieve the most objective and transparent form of expert decision-making [2, 4, 11, 13].

The shift toward digital expert systems also brings to light an essential dimension – the ethical implications of using digital patient replicas. The implementation of expert medical modeling (EMM) inevitably raises a complex set of ethical, legal, and psychological questions. Creating and utilizing digital copies of patients – so-called virtual twins – requires a well-defined regulatory and moral framework that ensures respect for human dignity, autonomy, and privacy. The ability to simulate a person's physiological and psychological state in silico blurs the boundary between clinical data and personal identity [10–12, 33].

First and foremost, informed consent must explicitly include provisions for the creation, processing, and potential reuse of digital replicas. Patients should be fully aware that a digital twin may persist and evolve beyond the duration of their physical treatment. Secondly, data ownership and control become key ethical issues: who owns the digital twin – the patient, the healthcare institution, or the software developer? Thirdly, algorithmic transparency and the right to explanation must be guaranteed, particularly when AI-driven conclusions influence clinical or legal decisions [3].

It is equally important to prevent the dehumanization of medical expertise. Digital models should support – not replace – the clinician's ethical responsibility. In this regard, expert medical modeling must adhere to the principles of the Declaration of Helsinki [34], the Oviedo Convention [35], and relevant national bioethical frameworks [4], ensuring that technology serves humanity – not the reverse.

Among the promising perspectives of this approach are the creation of a national archive of digital visualizations, the expansion of medical information system functionality, and the implementation of AI algorithms for image analysis. The development of such algorithms should be oriented toward addressing the specific needs of medical professionals and ensuring that the resulting models remain clinically relevant, interpretable, and ethically compliant.

Prognostic assessment and clinical decision-making based on large arrays of integrated and generalized indicators should be performed using artificial intelligence (AI) tools. This corresponds to the broader global trend of integrating AI into healthcare.

In Ukraine, the implementation of expert medical modeling (EMM) could become a cornerstone of the national strategy for integrating medicine, science, and digital transformation within the healthcare system. At the clinical level, EMM enables the creation of patient-specific digital twins for simulating treatment processes, forecasting surgical outcomes, and planning rehabilitation programs. In rehabilitation medicine, this approach allows clinicians to assess a patient's physiological tolerance to therapeutic loads, monitor recovery dynamics, and design personalized rehabilitation trajectories for veterans, civilians affected by war, and individuals with occupational diseases [4].

At the scientific level, EMM may serve as a foundation for developing large-scale databases of digital physiology, supporting interdisciplinary research across biomechanics, neuroscience, and psychophysiology. For expert medicine – including medical-social, military-medical, and forensic expertise – EMM provides a framework for standardizing and objectifying decision-making through automated analysis of digital physiological replicas, thereby minimizing the human factor and enhancing transparency [1–4, 10–13].

From an organizational perspective, the establishment of a national platform for medical digital visualization based on EMM could become an integral component of the Ukrainian electronic healthcare system. Such a platform would ensure interoperability between clinics, research institutions, and rehabilitation centers; promote the application of blockchain technologies for data protection; and accelerate the adoption of AI-driven tools for image analysis and predictive modeling [5, 9, 33].

Ultimately, the use of EMM in Ukraine holds not only technological but also social significance – forming a new culture of digital medicine centered on the patient, their safety, and the quality of recovery.

CONCLUSIONS

1. Modern domestic clinical practice demonstrates insufficient consistent use of digital media: images often remain in the form of printed conclusions, and digital formats are not integrated into medical information systems.
2. There is an urgent need in Ukraine to introduce digital media in all areas of healthcare and to create an integrated EMM.
3. A promising direction is the formation of personalized models of the patient based on 3D/4D images for conducting expert tests using artificial intelligence technologies.
4. Increasing the digital competence of medical professionals is a prerequisite for the effective use of digital standards.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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