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ANALYSIS OF MODERN PROBLEMS OF BIOMEDICAL ENGINEERING

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Abstract: The article analyzes the key problems currently facing biomedical engineering, based on a review of international and national scientific literature. The problems were grouped into five categories: regulatory and safety issues of medical devices, the validation and transparency of artificial intelligence technologies, cybersecurity and data protection, the technology gap and medical equipment management in low- and middle-income countries, and workforce and educational challenges. For each category, the causes, consequences and possible solutions are discussed. The study concludes that overcoming these problems requires an integrated approach combining regulation, international cooperation, technology adapted to local conditions and the modernization of biomedical education.
Keywords: biomedical engineering, medical devices, regulation, artificial intelligence, cybersecurity, healthcare technology management, medical education.

Аннотация: В статье на основе обзора международной и отечественной научной литературы проанализированы ключевые современные проблемы биомедицинской инженерии. Проблемы сгруппированы в пять категорий: регулирование и безопасность медицинских изделий, валидация и прозрачность технологий искусственного интеллекта, кибербезопасность и защита данных, технологический разрыв и управление медицинским оборудованием в странах с низким и средним уровнем дохода, кадровые и образовательные проблемы. Для каждой категории рассмотрены причины, последствия и возможные пути решения.
Ключевые слова: биомедицинская инженерия, медицинские изделия, регулирование, искусственный интеллект, кибербезопасность, медицинское образование.

Annotatsiya: Maqolada xalqaro va mahalliy ilmiy adabiyotlar sharhi asosida biotibbiyot muhandisligining zamonaviy asosiy muammolari tahlil qilingan. Muammolar beshta toifaga ajratildi: tibbiy buyumlarni tartibga solish va xavfsizligi, sun’iy intellekt texnologiyalarini validatsiya qilish va shaffofligi, kiberxavfsizlik va ma’lumotlarni himoya qilish, texnologik tafovut va tibbiy asbob-uskunalarni boshqarish, kadrlar va ta’lim muammolari. Har bir toifa bo‘yicha sabablar, oqibatlar va yechim yo‘llari ko‘rib chiqildi.
Kalit so‘zlar: biotibbiyot muhandisligi, tibbiy buyumlar, tartibga solish, sun’iy intellekt, kiberxavfsizlik, tibbiyot ta’limi.

INTRODUCTION

Biomedical engineering is an interdisciplinary field that applies the principles and methods of engineering, physics and computer science to solve problems in medicine and biology [4]. Over recent decades it has given healthcare imaging systems, implantable devices, artificial organs, biomaterials and, more recently, digital and artificial intelligence (AI) technologies. These achievements have transformed diagnosis and treatment and have become an integral part of modern healthcare systems [5].

However, the rapid development of the field has also produced a number of complex problems. Increasingly sophisticated medical devices place new demands on regulatory systems [10, 11]; AI-based tools raise questions about validation, reliability and transparency [7, 9]; the connection of devices to hospital networks creates cybersecurity risks; and in many countries a large gap remains between available technologies and the capacity to use and maintain them [5, 6, 12].

These problems are directly linked to the training of specialists. National studies emphasize that information technologies are an important factor in improving the quality of medical education [1], that adaptive online learning systems can personalize training [3], and that involving students in research is essential for developing innovative potential in higher education [2].

The aim of this study is to identify, systematize and analyze the main modern problems of biomedical engineering and to outline possible ways of addressing them, with particular attention to the conditions of Uzbekistan.

MATERIALS AND METHODS

This study is a narrative literature review. The sources included peer-reviewed articles in international journals, textbooks, technical documents of the World Health Organization, regulatory acts and publications by national researchers.

Literature was searched in PubMed, Google Scholar, eLibrary and the WHO publication repository using the following keywords: “biomedical engineering”, “medical device regulation”, “artificial intelligence in medicine”, “medical device cybersecurity”, “healthcare technology management”, “low-resource settings”, “biomedical engineering education”. Priority was given to highly cited publications and official documents that address the problems of the field at a systemic level.

Methods of systematic and comparative analysis, generalization and content classification were applied. The identified problems were grouped by thematic category, and for each category causes, consequences and proposed solutions were analyzed.

RESULTS

The analysis made it possible to identify five main groups of modern problems in biomedical engineering (Table 1).

Table 1. Main groups of modern problems in biomedical engineering

Problem group	Essence of the problem	Possible solutions
Regulation and safety of medical devices	Differences between regulatory systems; increasing device complexity; limited post-market surveillance	Harmonization of standards; stronger clinical evidence requirements; vigilance systems
Validation of AI technologies	Retrospective evaluation; limited data diversity; low transparency of algorithms	Prospective multicenter trials; transparent reporting; continuous monitoring
Cybersecurity and data protection	Network-connected devices are vulnerable to attacks; risk of patient data leakage	Security by design; regular software updates; staff training
Technology gap and equipment management	Equipment unsuitable for local conditions; lack of maintenance and spare parts	Context-appropriate design; clinical engineering services; equipment management

		programs
Workforce and education	Shortage of biomedical engineers; weak integration of engineering and medical training	Interdisciplinary curricula; IT in education; student research involvement

Regulation and safety. A comparison of medical device regulation in the United States and the European Union showed substantial differences in pre-market requirements and in the level of clinical evidence required, which affects both patient safety and the speed of access to innovation [10]. The adoption of the new EU Medical Device Regulation 2017/745 reflects efforts to strengthen clinical evaluation and post-market surveillance [11].

Validation of artificial intelligence. AI algorithms have achieved specialist-level performance in individual tasks such as image classification [8]. However, an analysis of AI devices cleared by the US Food and Drug Administration found that most of them had been evaluated only retrospectively and that many evaluations were not multi-site, which limits confidence in their generalizability [9]. Topol also emphasizes the risks of bias, insufficient transparency and the gap between algorithmic accuracy and clinical benefit [7].

Technology gap and equipment management. WHO documents indicate a significant mismatch between the medical devices available on the market and the real needs and capacities of healthcare systems in low- and middle-income countries [6]. A considerable share of equipment in such settings is out of service because of a lack of maintenance, spare parts, consumables or trained personnel [6, 12]. Devices designed for high-income settings often fail under conditions of unstable power supply, high temperature and dust [12].

Workforce and education. The WHO notes a shortage of biomedical engineers in many countries and the absence of formal recognition of the profession in some health systems [5]. This makes it difficult to ensure the safe and efficient use of medical technology.

DISCUSSION

The results show that the problems of biomedical engineering are closely interconnected. For example, the introduction of AI-based devices simultaneously raises regulatory, cybersecurity and educational issues: such technologies require new evaluation methods, protected digital infrastructure and specialists who understand both the clinical and the technical side [7, 9].

For countries such as Uzbekistan, which are actively modernizing their healthcare systems, the problems of the technology gap and workforce shortages are particularly relevant. Purchasing modern equipment does not by itself guarantee better care: it must be accompanied by the development of clinical engineering services, maintenance systems and staff training [5, 6]. Malkin's work shows that technologies designed with local conditions in mind are more sustainable and cost-effective [12].

The modernization of education is a key condition for solving these problems. Integrating biophysics, medical informatics and the fundamentals of medical technology into the curricula of medical universities helps future physicians use complex equipment competently and work with engineers. The use of information and adaptive computer technologies improves the quality of training [1, 3], and the systematic involvement of students in research activities helps form a new generation of specialists capable of creating and evaluating innovative solutions [2].

A limitation of this study is its narrative-review design: it does not include a quantitative meta-analysis, and the selection of sources may be subject to the authors' judgment. Future work should

include empirical studies of the state of medical equipment management in healthcare institutions of Uzbekistan.

CONCLUSIONS

1. The main modern problems of biomedical engineering are related to the regulation and safety of medical devices, the validation of AI technologies, cybersecurity, the technology gap and equipment management, and workforce and education.

2. These problems are interconnected and require an integrated approach combining regulation, international cooperation, context-appropriate technology and investment in human resources.

3. For Uzbekistan, the priority tasks are developing clinical engineering services, establishing systems for medical equipment maintenance and training qualified specialists in biomedical engineering.

4. Modernizing medical education through information technologies, interdisciplinary teaching and student involvement in research is a key prerequisite for the sustainable development of the field.

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