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Spis treści Content

- AI in medicine: An analysis of threats, risks, and solutions for the future of healthca** 1–11
Zastosowanie AI w medycynie: analiza zagrożeń, ryzyka i rozwiązań dla przyszłości opieki
zdrowotnej
Helena Brawańska, Marta Jędrzejowska, Karolina Lau, Janusz Kasperczyk
- Attitudes towards eating disorders among medical and non-medical students from the
Silesian Voivodeship** 12–20
Postawy studentów kierunków medycznych i niemedycznych z województwa śląskiego wobec
problemu zaburzeń odżywiania
Mateusz Olek, Mateusz Ordowski, Julita Klag, Karolina Lau
- Corynebacterium diphtheriae – An underrated threat? An analysis of the epidemiological
risk of diphtheria in the 21st century** 21–30
Corynebacterium diphtheriae – niedoceniane zagrożenie? Analiza ryzyka epidemiologicznego
błonicy w XXI wieku
Magdalena Sulasz, Jakub Fiegler-Rudol, Karolina Lau, Janusz Kasperczyk
- Prebiotics: The foundation of preventive health care** 31–39
Prebiotyki – fundament profilaktyki zdrowotnej
Wiktoria Ficoń, Maksymilian Dobosz, Beata Całyniuk
- Assessment of body-esteem and attitudes toward various weight loss support methods
among young adult women and men** 40–50
Badanie poziomu samooceny ciała oraz stosunku do różnych metod wspomagania redukcji
masy ciała u młodych kobiet i mężczyzn
*Zofia Graca, Tomasz Wołoszczuk, Jakub Kołodziej, Aleksandra Skowronek, Karolina Lau,
Janusz Kasperczyk*
- Opportunity or threat? A comparative study on the perception of artificial intelligence
in dentistry among practitioners and patients** 51–58
Szanse czy zagrożenia? Badanie porównawcze postrzegania sztucznej inteligencji w stomatologii
wśród lekarzy i pacjentów
Milosz Krysiak, Katarzyna Drobny
- Primary pericardial mesothelioma: A cancer without prognosis? An epidemiological
and clinical challenge** 59–65
Pierwotny międzybłoniak osierdza: nowotwór bez rokowania? Wyzwanie epidemiologiczne
i kliniczne
*Estera Pazeł, Michał Sikorski, Michał Kapalka, Michał Krawiec, Grzegorz Hirnle,
Tomasz Hrapkowicz*
- Bruxism in young adults (aged 18–25): The role of stress and other psychological factors** 66–72
Bruksizm u młodych dorosłych (18–25 lat) – rola stresu i innych czynników psychologicznych
Piotr Ziobro, Justyna Zientek, Jakub Fiegler-Rudol, Karolina Lau



- ⌚ Experiences of discriminatory behavior in reproductive care: Preliminary study findings** 73–82
Doświadczenia dyskryminacyjnego traktowania w opiece reprodukcyjnej – wstępne wyniki badania
Martyna Szymańska, Piotr Romaniuk
- ⌚ The presence of antibiotics in food and the consequences for human health** 83–92
Obecność antybiotyków w żywności i jej konsekwencje dla zdrowia człowieka
Dominika Nicz, Gabriela Mysiek, Katarzyna Lis, Janusz Kasperczyk
- ⌚ One patient, multiple cardiac implantable devices, a shared threat: T-wave oversensing in the course of hyperkalemia** 93–97
Jeden pacjent, wiele kardiologicznych urządzeń wszczepialnych, wspólne zagrożenie: *oversensing* załamka T w przebiegu hiperkaliemii
Michał Krawiec, Aleksandra Hakało, Agnieszka Radziewicz, Oliwia Jewuła, Ewa Jędrzejczyk-Patej, Beata Średniawa



AI in medicine: An analysis of threats, risks, and solutions for the future of healthcare

Zastosowanie AI w medycynie: analiza zagrożeń, ryzyka i rozwiązań dla przyszłości opieki zdrowotnej

Helena Brawańska¹ , Marta Jędrzejowska¹ , Karolina Lau² , Janusz Kasperczyk²

¹Students' Scientific Club, Department of Environmental Medicine and Epidemiology, Faculty of Medical Sciences in Zabrze, Medical University of Silesia, Katowice, Poland

²Department of Environmental Medicine and Epidemiology, Faculty of Medical Sciences in Zabrze, Medical University of Silesia, Katowice, Poland

ABSTRACT

Artificial intelligence (AI) is playing an increasingly significant role in medicine, impacting diagnostics, treatment, and the organization of healthcare systems. This paper analyzes the potential benefits and risks associated with the use of AI in medicine. It focuses on technical, ethical, and regulatory aspects, as well as the impact of AI on patient safety and the effectiveness of clinical decision-making. A comprehensive literature review was conducted in the PubMed, Scopus, and Google Scholar databases, considering publications from 2019 to 2025. A qualitative synthesis of the 52 selected articles identified key challenges and recommendations for further research and implementation of AI in healthcare. The analysis indicates that AI significantly improves diagnostic precision and therapy efficiency, while also posing risks of algorithmic errors, model bias, and breaches of patient privacy. Effective implementation of AI requires legal regulations, clear application guidelines, and multidisciplinary collaboration among experts. Future research should focus on developing mechanisms to increase trust in AI systems and ensure their responsible use in medicine.

KEYWORDS

artificial intelligence in medicine, AI risks, AI ethics, data security, AI legal regulations, machine learning

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Address for correspondence: Helena Brawańska, Studenckie Koło Naukowe, Katedra i Zakład Medycyny i Epidemiologii Środowiskowej, Wydział Nauk Medycznych w Zabrze SUM, ul. Jordana 19, 41-808 Zabrze, tel. +48 507 960 796, e-mail: s85617@365.sum.edu.pl



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STRESZCZENIE

Sztuczna inteligencja (*artificial intelligence* – AI) odgrywa coraz większą rolę w medycynie, wpływając na diagnostykę, leczenie oraz organizację systemów opieki zdrowotnej. W pracy przeanalizowano potencjalne korzyści oraz zagrożenia związane z wykorzystaniem AI w medycynie. W szczególności skupiono się na aspektach technicznych, etycznych i regulacyjnych, a także na wpływie AI na bezpieczeństwo pacjentów oraz skuteczność podejmowanych decyzji klinicznych. Przeprowadzono kompleksowy przegląd literatury w bazach danych PubMed, Scopus i Google Scholar, uwzględniając publikacje z lat 2019–2025. Na podstawie wyselekcjonowanych 52 artykułów dokonano jakościowej syntezy wyników, identyfikując kluczowe wyzwania oraz rekomendacje dotyczące dalszych badań i wdrażania AI w opiece zdrowotnej. Wyniki analizy wskazują, że AI znacząco zwiększa precyzję diagnostyczną i skuteczność terapii, jednocześnie niesie za sobą ryzyko błędów algorytmicznych, stronniczości modeli oraz naruszenia prywatności pacjentów. Skuteczne wdrożenie AI wymaga uregulowań prawnych, przejrzystych zasad stosowania oraz współpracy ekspertów z różnych dziedzin. Przyszłe badania powinny koncentrować się na opracowaniu mechanizmów zwiększających zaufanie do systemów AI i zapewniających ich odpowiedzialne wykorzystanie w medycynie.

SŁOWA KLUCZOWE

sztuczna inteligencja w medycynie, ryzyko związane z AI, etyka AI, bezpieczeństwo danych, regulacje prawne AI, uczenie maszynowe

INTRODUCTION

Artificial intelligence (AI) is revolutionizing medicine by supporting diagnostics, medical documentation, and therapy-related decision-making [1]. AI refers to the field of computer science dealing with systems capable of performing tasks that typically require human intelligence, such as data analysis, pattern recognition, and decision-making [2]. Among its applications, AI-based clinical decision support systems (AI-CDSSs) are gaining increasing importance by assisting medical staff in clinical decisions through algorithms that analyze patient data [3,4].

One of the key areas of AI is machine learning (ML), which allows computers to analyze data and improve their performance without manual programming. There are two main approaches: supervised learning, which uses labeled data for training, and unsupervised learning, which analyzes unlabeled data to find hidden patterns [5]. A more advanced form of ML is deep learning (DL), based on multi-layered artificial neural networks processing vast amounts of data. Each layer transforms information and successive analyses lead to increasingly abstract conclusions until the final result is obtained [6]. DL is widely used in imaging diagnostics, where AI systems analyze medical images to detect pathologies [7].

Generative models form a separate category capable of creating new data based on existing patterns. They work by modeling the probability distribution of input data and generating new samples with similar features. In medicine, they are used to synthetically generate diagnostic images (e.g., magnetic resonance imaging [MRI], computed tomography [CT], or electroencephalogram [EEG] scans), which can facilitate AI training and improve performance in tasks such as detecting pathological changes [2,8].

However, synthetic data – despite its usefulness – can lead to distortions in algorithm performance. Models trained solely on synthetic data often perform poorly at analyzing real-world data. This is because synthetic data may not reflect the full complexity, variability, and significant features of real medical records, leading to generalization issues and higher risk of diagnostic errors. This phenomenon, known as domain mismatch, is a major challenge for the safe, reliable development of AI systems in medicine [9,10].

AI brings numerous benefits to medicine, especially in diagnostics, pathology, and telemedicine. In radiology, AI algorithms assist in analyzing x-rays, CT scans, and MRIs, enhancing the efficiency of detecting diseases such as lung disease, cancer, and bone fractures [11]. In oncology, AI is used in screening tests, such as mammography, improving breast cancer detection rates and reducing false positives. In pathology, AI analyzes histopathological images, identifying tumors (e.g., gliomas or lymphomas) with up to 96% accuracy [6,12]. In cardiology, AI supports analysis of electrocardiograms (ECGs), echocardiograms, and cardiac MRIs, allowing for earlier detection of arrhythmias and coronary syndromes [11]. Telemedicine applications enable remote patient monitoring, analysis of test results, and diagnostic support in areas with limited access to medical professionals [6].

However, the rapid development of AI poses challenges regarding regulation, transparency, and data security. Legal frameworks like the European Union's (EU) Artificial Intelligence Act (AI Act) classify medical AI systems as high-risk technologies and establish requirements for human oversight, transparency, and performance monitoring. In the USA, the Food and Drug Administration's (FDA) Artificial Intelligence/Machine Learning-based Software as a Medical Device Action Plan (AI/ML-based SaMD Action Plan) mandates model auditing



and clinical robustness. Data protection is governed by law (the Health Insurance Portability and Accountability Act [HIPAA] in the USA and the General Data Protection Regulation [GDPR] in the EU) and best practices are outlined in the Good Machine Learning Practices (GMLP) [13,14].

Tools such as GPT-4 can enhance healthcare efficiency, but also introduce risks that demand regulation and informed governance. The aim of this paper is to analyze major threats associated with AI in medicine, including AI hallucinations, diagnostic errors, algorithmic biases, lack of transparency, and cybersecurity issues. As the technology advances, understanding its limitations and implementing safety strategies becomes crucial [9,15,16].

MATERIAL AND METHODS

Research scope and research area

This narrative review explores the opportunities, challenges, and regulatory concerns related to the use of AI in clinical practice. The guiding research question was, “How does the use of artificial

intelligence in medicine impact patient safety, diagnostic and therapeutic effectiveness, and ethical/legal standards in healthcare systems?” The study addressed various dimensions, including technical reliability, clinical outcomes, legal compliance, ethical risks, and data privacy, focusing on the systems used in diagnostics, decision support, and therapy planning.

Literature search strategy

We conducted a structured literature review using the databases PubMed, Scopus, and Google Scholar, covering publications from 2019 to 2025. Both Medical Subject Headings (MeSH) and free-text keywords were used to ensure comprehensiveness. The search strategy focused on interdisciplinary terms connecting artificial intelligence with medical practice, legal regulations, and bioethics. The primary MeSH terms are presented in Table I.

Inclusion and exclusion criteria

We applied specific inclusion and exclusion criteria, outlined in Table II, to ensure the relevance and quality of the studies we included.

Table I. MeSH keywords used in this review

AI fundamentals	“artificial intelligence”, “machine learning”, “deep learning”, “neural networks (computer)”, “generative models”
Clinical application areas	“diagnosis, computer-assisted”, “radiology”, “oncology”, “cardiology”, “telemedicine”, “clinical decision support systems”
Risk and ethics	“ethics, medical”, “data privacy”, “confidentiality”, “informed consent”, “bias, algorithmic”, “trust”
Legal and regulatory context	“legislation, medical”, “regulatory compliance”, “medical device regulation”, “liability, legal”
Safety and system performance	“patient safety”, “reproducibility of results”, “software validation”, “adverse events reporting”

Table II. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Peer-reviewed studies on real-world applications of AI in medicine	Articles unrelated to medical AI or not relevant to healthcare practice
Studies analyzing AI’s impact on patient safety, clinical decision-making, or diagnostic accuracy	Opinion pieces, commentaries, or non-empirical papers
Papers discussing legal, ethical, and regulatory aspects of AI in healthcare	Conference abstracts, letters to the editor, or inaccessible full texts
Reviews or meta-analyses with methodological transparency	Articles lacking outcome-based data or specific discussion of AI mechanisms
Documents referring to AI legislation (e.g., the AI Act, HIPAA, the GDPR, or the MDR)	Publications not in English or Polish without a verified translation

AI – artificial intelligence; HIPAA – Health Insurance Portability and Accountability Act; GDPR – General Data Protection Regulation; MDR – Medical Devices Regulation.

Data synthesis and categorization

Articles were classified into thematic domains reflecting the main challenges and areas of AI implementation in medicine. The categorization was aligned with the analytical framework presented in the

following section and it included the following four categories:

1. AI in clinical diagnostics and decision support systems (e.g., imaging interpretation, risk stratification tools, or early disease detection)



2. Ethical, legal, and regulatory challenges (e.g., liability in algorithm-based decisions, informed consent, or transparency standards)
3. Data privacy, cybersecurity, and model robustness (e.g., adversarial attacks, bias mitigation, or reproducibility problems)
4. Patient experience and system integration (e.g., hybrid models in practice, overreliance on automation, or equity in access to AI tools)

Legal acts, strategic documents, selected foundational reviews, and key regulatory guidelines (e.g., the AI Act, GMLP, HIPAA, or the GDPR) were analyzed to support the conceptual framework and provide context for thematic classification and regulatory interpretation.

Elaboration of results and synthesis

Each category was discussed in terms of benefits, limitations, barriers to implementation, and identified research gaps. Due to the methodological heterogeneity of the included studies, no quantitative meta-analysis was performed. A visual outline of the review process and analytical stages is presented in Figure 1.

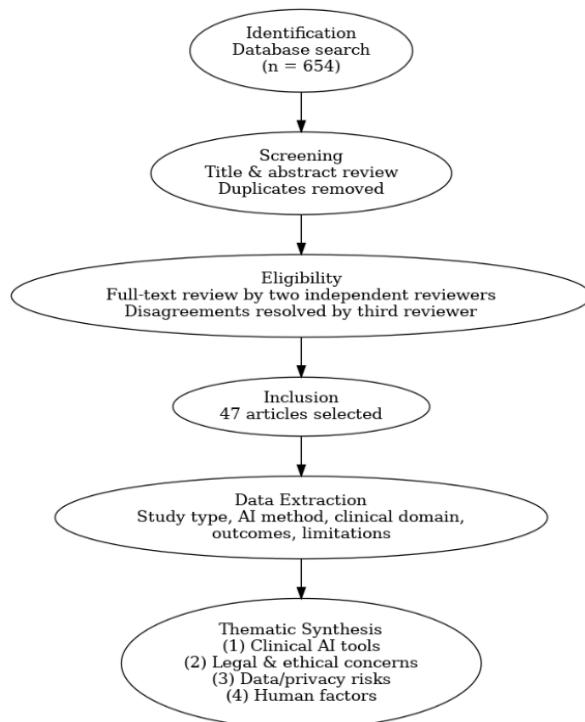


Fig. 1. Research methodology.

LEGAL AND REGULATORY ASPECTS OF AI USE IN MEDICINE

The application of AI in medicine requires the consideration of numerous legal conditions and regulatory standards aimed at protecting patients, ensuring transparency about the algorithms, and assigning responsibility to the entities involved. Due to the potential health and safety risks, AI systems used in medicine are classified as high-risk technologies and are subject to strict oversight [14,17].

In the EU, the key legal framework is the AI Act, which defines rules for AI usage based on risk levels. Systems used in healthcare, including diagnostics and treatment, are classified as high-risk, requiring compliance with stringent requirements. The AI Act mandates human oversight, algorithm transparency, auditability of decision-making processes, and operational risk management [17].

These requirements are further elaborated in the GMLP, a set of guidelines developed by organizations such as the FDA and international bodies assessing ML systems. GMLP emphasizes data quality, version control of models, algorithmic transparency, and the ability to monitor and audit systems in clinical environments [13]. Additionally, a Predetermined Change Control Plan is required, which defines the rules for modifying algorithm behavior without compromising user safety.

Data protection obligations are regulated by the GDPR in the EU and HIPAA in the USA. These regulations impose specific duties on entities processing medical data, which is recognized as sensitive information. The use of AI for processing such data requires explicit patient consent, anonymization mechanisms, and compliance with principles such as data minimization, transparency, and limitation of purposes [18,19].

AI systems performing diagnostic or therapeutic functions are also covered by the EU Medical Devices Regulation (MDR), which classifies medical software (including AI) as medical devices and imposes obligations regarding certification, clinical evaluation, and safety [20]. Likewise, the FDA has implemented the AI/ML-based SaMD Action Plan, which includes risk assessment, clinical validation, continuous monitoring, and verification of algorithm performance in real-world settings [21].



Mental health support applications using AI, while not always classified as medical devices, can still pose risks to user safety. According to Articles 6 and 14 of the AI Act, if these systems threaten fundamental rights or user health, they must be treated as high-risk and comply with evaluation and transparency standards. If such an application has diagnostic or therapeutic functionality, it may also fall under the MDR, requiring conformity and clinical safety assessment procedures. When the tool is not considered a medical device, GDPR provisions still apply [18]. In the USA, such apps are often beyond FDA oversight unless they meet the SaMD definition, which would require a clinical impact assessment and compliance with FDA guidelines [21].

Another important issue is the attribution of responsibility for decisions made by AI. According to the draft EU directive, liability may be shared among the front-end operator (e.g., physician), back-end operator (system provider), and software manufacturer. Each party is required to oversee the system, report incidents, and ensure data input quality. In practice, this means that in case of a diagnostic error caused by AI, responsibility may lie with the user, the system developer, or the implementing institution [14].

AI HALLUCINATIONS AND THE GENERATION OF FALSE INFORMATION

One of the most serious threats related to the implementation of artificial intelligence in healthcare is the generation of incorrect or fabricated information by AI models, particularly generative ones. For instance, AI can incorrectly diagnose cancer based on an x-ray image, leading to unnecessary medical procedures [1,22].

As discussed in the legal section, AI systems classified as high-risk are subject to human oversight, event logging, and strict transparency requirements, including compliance with GMLP [13]. To reduce the occurrence of AI hallucinations, it is crucial to use diverse, representative data sets and to conduct independent clinical validations. Standards such as CONSORT-AI and SPIRIT-AI help ensure transparency and reliability in reporting study results involving AI models, thereby reducing the risk of inaccurate diagnostic recommendations [23].

LACK OF TRANSPARENCY REGARDING ALGORITHMS (BLACK BOX PROBLEM)

AI models often function as a “black box,” meaning that their decision-making processes are not transparent. This can lead to distrust and difficulties in

assessing the risk of error [24]. In the event of an incorrect diagnosis, it becomes unclear who is responsible: the physician, the software developer, or the medical institution. The opacity of AI models also makes it difficult for doctors to trust their recommendations [25].

As discussed above, the EU’s AI Act, the FDA’s AI/ML-based SaMD Action Plan, and GMLP require that high-risk systems be audited – subject to human oversight – and provide interpretability wherever possible. These regulations aim to increase accountability and allow clinicians to make decisions based on understandable input and algorithm outputs [13,14].

One proposed solution to the black box problem is Explainable Artificial Intelligence (XAI), which aims to enable users to understand why an algorithm made a specific decision. However, the development of such solutions remains limited – especially in the case of complex DL models, where interpreting the functioning of neural networks remains challenging [26].

In clinical practice, hybrid models are increasingly being used; they combine AI capabilities with traditional medical knowledge and physician experience. This approach fosters collaboration between the algorithm and the specialist – AI analyzes the data (e.g., imaging or lab results), but the final interpretation and therapeutic decision remain in human hands. Hybrid models increase physicians’ trust in technology because they support rather than replace the physician’s role and they improve interpretability and legal compliance [27,28]. Such solutions promote the responsible, flexible use of AI in everyday clinical practice [29].

REPRODUCIBILITY ISSUES IN AI-GENERATED RESULTS

Reproducibility is a cornerstone of medical practice, yet AI systems often generate different outcomes even when analyzing identical data. This can lead to ambiguous diagnoses and inconsistent therapeutic recommendations [30]. In a study on cancer diagnostics, it was found that AI algorithms analyzing the same MRI scans produced contradictory results due to minor differences in input parameters [16].

As discussed in the legal section, EU legislation (the AI Act and the MDR) obliges AI system manufacturers to ensure the stability of their models and to document the decision-making process. The draft directive on AI liability also requires access to documentation from which the algorithm’s decision can be reconstructed [14]. To enhance consistency, it is necessary to implement mechanisms for “freezing” model versions and maintaining version control of



algorithms. This can help reduce the risk of non-reproducible outcomes [16].

DATA QUALITY AND DIAGNOSTIC ERRORS

AI systems learn from historical data, which are often incomplete, biased, or unrepresentative. These limitations can lead to serious diagnostic errors [23,31,32]. One example is reduced accuracy in detecting skin cancer in patients with darker skin tones, because training datasets primarily included images of lighter-skinned individuals [24,30]. Another case involved an AI model used to assess pneumonia risk, which incorrectly assumed that asthma patients had a lower risk of complications because they typically received more intensive care [33]. In oncology, AI systems have shown lower detection rates for tumors in women from ethnic minorities, as the training data came mostly from white patients [34]. Additionally, some algorithms may misinterpret textual data, resulting in diagnostic errors. For instance, a system analyzing electronic health records misclassified a patient's occasional alcohol consumption as alcohol addiction, which led to exclusion from a liver transplant list [25].

Another issue is the limited portability of models across regions. Algorithms trained on data from the USA may underperform in other countries, and those trained in English may struggle to interpret medical records in other languages [14].

As outlined in the legal and regulatory section, regulations such as Article 10 of the AI Act and GMLP require AI developers to monitor data quality, manage data sources, and eliminate algorithmic bias [13]. The use of a Predetermined Change Control Plan is crucial to avoid uncontrolled changes in model performance. The use of systematic algorithm audits and diverse training datasets are also recommended [34], significantly improving diagnostic accuracy and patient safety.

OVERRELIANCE ON AI AND THE DEHUMANIZATION OF MEDICINE

While AI supports diagnostic and therapeutic decisions, excessive reliance on it can lead to negative consequences. For example, an AI system used for diagnosing heart disease overlooked critical clinical factors, resulting in incorrect therapeutic recommendations [1]. Studies show that physicians using AI-assisted radiological image analysis are more likely to miss significant abnormalities when relying blindly on algorithmic suggestions [35]. This phenomenon, known as “cognitive automation,” may limit critical thinking in clinical practice. Physicians,

convinced of AI's accuracy, might lower their diagnostic vigilance, thus compromising the quality and safety of care [1]. Furthermore, over-automation of the diagnostic process can adversely affect the doctor–patient relationship. Human contact becomes limited and decisions are based on data analysis without considering the patient's individual experiences and needs. Patients may feel reduced to a data set, which can diminish empathy and trust in the treatment process [26]. This issue is also discussed in the legal context, where Article 14 of the AI Act requires that the final medical decision be made by a human – not by an algorithm [27].

THREATS IN AI APPLICATIONS THAT SUPPORT MENTAL HEALTH

Generative AI is increasingly being used in wellness applications that support mental health. Although these tools can complement traditional therapy, studies indicate that improper functioning may lead to serious consequences. For example, AI chatbots have been reported to respond inappropriately to suicidal thoughts. In one study involving five popular AI-based mental health apps, 50% of them failed to provide any assistance and, in extreme cases, responses exacerbated the crisis – such as replying “Don't u coward” to suicidal ideation [36]. AI may also misjudge a patient's condition and fail to direct them to professional help.

The legal requirements for such tools are detailed in the section on legal and regulatory aspects above. These include the classification of such applications as high-risk systems under the AI Act, the possibility of categorization as medical devices under the MDR, and the obligations stemming from the GDPR and FDA regulations in the USA. The lack of a unified regulatory approach to AI-powered wellness apps creates risks for users, especially in mental health support. As a result, both in the EU and the USA, there is growing advocacy for stricter regulation and mandatory referral to professional help in crisis situations [36,37].

CYBERSECURITY AND PROTECTION OF PATIENT DATA

AI systems in medicine operate on large datasets containing sensitive information, such as personal data, imaging results, genetic data, or medical histories. Due to their confidential nature, these data are an attractive target for cybercriminals, making AI systems particularly vulnerable. Although modern ML models are highly effective at data analysis, they are also susceptible to various types of attacks that can



result in serious privacy breaches and diagnostic errors [38,39]. One of the most dangerous threats is adversarial attacks, which involve introducing subtle, often imperceptible changes to medical images. These manipulations can completely mislead the algorithm, resulting in misclassifications or incorrect diagnoses – even with a confidence level of 99% [38,40]. Another risk includes membership inference attacks, which aim to determine whether a specific patient's data was used in model training. Such intrusions can lead to the disclosure of personal or health-related information [41]. Model inversion attacks also pose a threat, as they can partially reconstruct input data – such as an MRI image – compromising patient privacy and violating data protection regulations [42].

With the growing role of health data in training AI models, there is an increasing risk of commercial misuse. Technology companies are increasingly leveraging data collected from mobile apps, wearables, or diagnostic systems – not only for medical purposes, but also for marketing and often without the patient's full awareness of this use of their data. As Kanter and Packel [43] note, privacy is often infringed within vague legal boundaries and patients do not always have real control over how their data are utilized. Rajpurkar et al. [44] highlight the need to develop clear oversight and control mechanisms for AI models processing health data. This is especially important in the case of wellness apps or AI chatbots that do not formally fall under medical device regulations. Consequently, patients may unknowingly consent to the use of their data for non-medical purposes, undermining trust in the patient–technology relationship.

Access to medical data is regulated by HIPAA (USA), the GDPR (EU), and the AI Act, which specify who may process patient data and under what conditions. The AI Act introduces additional safeguards to prevent unauthorized access to sensitive data, thereby enhancing protection [13]. Ensuring cybersecurity must be a top priority, particularly in the context of regulations such as GDPR and HIPAA, which mandate the protection of patient data. Risk minimization requires the use of advanced encryption technologies, multi-factor authentication, and real-time user activity monitoring. Some hospitals implement early warning systems that detect unusual access patterns and automatically block suspicious activity [43,44].

INFORMED PATIENT CONSENT FOR THE USE OF AI

Medical law requires that informed consent be obtained from patients for all medical interventions, which also includes the use of AI in diagnosis and

treatment. It is essential that the patient is properly informed about the role of AI in the clinical decision-making process, its potential limitations, associated risks, and available therapeutic alternatives. This approach is reflected in both legal regulations and policy documents, such as the AI Act and the “White Paper on AI in Clinical Practice” [14].

As technology develops, patients are increasingly becoming active users of AI systems – using health monitoring applications, self-diagnosis tools, and remote therapeutic support systems. However, this role requires appropriate education and support. A low level of digital literacy and a lack of understanding of algorithmic operations can lead to misinterpreted results and improper use of technology, especially among older individuals or those who are digitally excluded. Lichosik [45] emphasizes that medical personnel should act as guides through technology: supporting patients in making informed decisions and overseeing the functioning and use of AI systems in clinical practice. Many currently available solutions are not user-friendly – they are too complex and poorly adapted to the realities of underdeveloped healthcare facilities [4].

In this context, increasing attention is being paid to the need to distinguish between general consent, related to traditional medical procedures, and so-called technological consent, which pertains specifically to the use of AI tools such as AI-CDSSs. This consent should inform patients of how the algorithm works, its limitations, its level of autonomy, and who is responsible for the decisions it makes [14,30,39]. Transparency regarding the functioning of AI is a necessary condition for ensuring truly informed consent: the patient must know how their data is processed and how it affects clinical decisions [39]. As noted by Amann et al. [29], the explainability of algorithms is the foundation of trust and ethical AI use in healthcare.

COSTS AND INEQUALITIES IN ACCESS TO AI

One of the challenges of implementing AI in medicine is the high cost, which can exacerbate inequalities in access to modern diagnostics. The EU foresees subsidizing the implementation of AI in public healthcare, as well as programs for standardizing access [14]. European regulations emphasize the need to ensure equal access to AI and to eliminate financial barriers, for example, through state subsidies [27]. Studies published in *Health Technology Assessment* indicate that integrating artificial intelligence can involve a significant investment of time and money. This process requires thorough testing and validation to ensure proper system performance in real clinical conditions [46]. Including AI in reimbursement



strategies that promote value-based care could provide significant incentives for the development and implementation of validated algorithms. In developed countries, the private sector is showing interest in investing in AI and other innovative healthcare technologies. Nevertheless, the high costs associated with purchasing scanners for digitizing histopathological specimens and specialized computer equipment pose a significant barrier to the adoption of AI tools in everyday clinical practice, especially in smaller and underfunded facilities. Additionally, the development of large, centralized image archives and databases, along with the purchase of hardware and software, requires substantial capital investment – which may be unattainable for smaller institutions [46,47].

The failure to consider local conditions and the limited resources of smaller medical facilities may lead to increasing disparities in access to advanced technologies. Research shows that AI-CDSS systems implemented in clinics and hospitals with limited infrastructure often turn out to be misaligned with the local context: they fail to account for real-world resources and are overly complex or poorly integrated with existing systems [4]. As a result, these technologies are used less frequently or completely abandoned, which can lead to the digital exclusion of smaller centers, further deepening existing disparities in the quality of healthcare services [3].

Although the implementation of AI in daily diagnostics involves considerable costs, it also brings about numerous benefits. The use of this technology can ultimately reduce healthcare expenses by limiting the need to repeat costly tests and minimizing the risk of errors. AI also increases access to specialized medical care, particularly in regions with shortages of healthcare personnel. Advanced analytical technologies can automate many routine diagnostic tasks, such as analyzing medical images, which reduces professionals' workloads and lowers the costs of conducting and interpreting tests. Medical errors, including incorrect interpretations of results, can generate additional expenses and delay treatment. Through precise data analysis, AI helps to reduce such occurrences. Furthermore, patient monitoring systems can also decrease the number of doctor's visits and hospitalizations, directly translating into reduced overall healthcare costs. Studies published in *Health Affairs* and the *Journal of the American College of Radiology* show that using AI in radiology can lower diagnostic costs by up to 20% and can reduce the error rate by up to 15%, significantly contributing to reduced treatment expenses [46].

CONCLUSIONS AND PROSPECTS

The application of AI in medicine entails both hope and serious controversy. Modern technology offers solutions with much diagnostic, analytical, and organizational potential. However, its responsible integration into clinical practice must be based on a critical perspective – one that considers both its limitations and the ethical boundaries of implementation.

Limitations of the approach and sources

Although this work adopted a narrative approach, a wide range of literature was utilized, including sources from both highly developed countries and those with limited access to advanced technologies (e.g., Poland, Croatia, Germany, and the United Kingdom). Nevertheless, there is a risk of selectivity and a lack of empirical data regarding local implementations of AI. A more systematic approach is needed to assess the quality of data [44].

Recommendations for practice and future research

1. Adapting AI to clinical realities – AI solutions should take into consideration the conditions of smaller facilities: their infrastructure, staffing levels, and degree of digitalization [4].
2. Increasing focus on education and digital literacy – Misunderstanding how AI systems work, among both physicians and patients, may lead to incorrect clinical decisions and a lack of trust [45].
3. Developing responsibility and oversight frameworks – Clear regulations are needed to define accountability for decisions made with the use of AI. There is also a need to standardize auditing tools for algorithms.
4. Interdisciplinary implementation teams – Only collaboration between physicians, computer scientists, ethicists, and legal experts can ensure that AI is implemented with respect for clinical and humanistic values [30].
5. Explainable AI as a necessary condition – Technology must be not only effective, but also understandable. A physician cannot make decisions based on a “black box” without the ability to verify the algorithm's reasoning [25].
6. Technological consent – Patients should be informed about the fact that decisions regarding their therapy are partially supported by an AI system, in addition to any medical risks [39].



7. Support for participatory research (co-design) – It is recommended to conduct research involving doctors, nurses, and patients even at the design stage of AI tools. This approach enhances the acceptability, effectiveness, and alignment of solutions with clinical realities. It better adapts the technology to the actual needs of users and increases their engagement and trust in new systems [48,49].
8. Strengthening education in ethics and AI in medicine – Introducing educational modules that address not only the technical aspects, but also the ethical, legal, and communication issues related to the use of AI can help prepare future doctors for the responsible, informed use of these tools [50,51].

Limits to AI development in medicine

Technological advancement must not become an end in itself. Not everything that is technically possible should be uncritically implemented in healthcare. Examples such as incorrect recommendations from mental health chatbots [36] or racial and gender biases in algorithms [35] show that without proper oversight, AI can cause real harm. The limits are defined not only by computational capabilities, but primarily by issues of trust, patient dignity, and physician autonomy. The dehumanization of the doctor–patient relationship, the decline of clinical experience, or the risk of digital exclusion are costs that must not be accepted in the name of efficiency.

Critical conclusions

The development of AI in medicine should be conscious, gradual, and guided by caution. Technology may support the physician, but it should not replace clinical judgment. The usefulness of algorithms must be balanced with their explainability and social, ethical acceptance. AI should not serve to justify cost-cutting measures that worsen the quality

of care; it must be a tool that supports responsible and integrated medical practice.

A key direction for future research should therefore not only be the development of algorithms, but also an understanding of how they are perceived and interpreted in real clinical settings. The future of AI depends on whether it can be rooted in the values defined by medicine: respect, safety, and patient dignity.

SUMMARY

The conclusions lead to a clear picture: artificial intelligence offers numerous benefits in terms of improving the effectiveness and accessibility of medical services, but it also entails real risks. Algorithms can streamline diagnosis and support clinical decisions, but they are not immune to errors, biases, or interpretation issues. Uncontrolled automation may diminish the physician's role, while unclear legal responsibility increases the risks for both patients and institutions.

Responsible AI implementation requires both advanced technology and well-thought-out legal, ethical, and organizational frameworks. It is necessary to build public trust, develop transparent operational mechanisms, and involve interdisciplinary teams in the design and testing of tools. In the coming years, special attention must be paid to researching how AI systems are understood and accepted by users in clinical practice. It will be equally important to adapt technology to local conditions and to foster open dialogue between the developers, users, and beneficiaries of AI systems. Only such an approach will allow for the real, safe, and equitable utilization of AI's potential in healthcare.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author's contribution

Study design – J. Kasperczyk, K. Lau, H. Brawańska

Data collection – H. Brawańska, K. Lau

Manuscript preparation – H. Brawańska, M. Jędrzejowska, J. Kasperczyk

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Final approval of the version to be published – J. Kasperczyk, H. Brawańska, M. Jędrzejowska



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Attitudes towards eating disorders among medical and non-medical students from the Silesian Voivodeship

Postawy studentów kierunków medycznych i niemedycznych z województwa śląskiego wobec problemu zaburzeń odżywiania

Mateusz Olek¹ , Mateusz Ordowski¹, Julita Klag¹, Karolina Lau² 

¹Students' Scientific Club, Department of Environmental Medicine and Epidemiology, Faculty of Medical Sciences in Zabrze, Medical University of Silesia, Katowice, Poland

²Department of Environmental Medicine and Epidemiology, Faculty of Medical Sciences in Zabrze, Medical University of Silesia, Katowice, Poland

ABSTRACT

INTRODUCTION: Eating disorders (EDs) are considered one of the most widespread health issues, characterized by a complex clinical presentation, risk factors, and consequences. The aim of the study was to examine the attitudes and opinions of students from medical versus non-medical fields in the Silesian Voivodeship regarding the issue of EDs.

MATERIAL AND METHODS: The research questions were distributed in the form of an online questionnaire. The study included 217 participants, and the data were analyzed using MS Excel and Statistica.

RESULTS: No statistically significant relationship was found between medical and non-medical students regarding their focus on eating habits, need for dietary changes, or self-assessed EDs knowledge. Students in earlier years showed a significantly higher tendency to observe their eating behavior. Nearly half of the respondents reported having experience of an ED; they were significantly more common among women. A total of 87.6% considered EDs an important social and public health issue. Most knew someone affected by ED, but either could not determine whether these individuals are socially excluded or stigmatized or stated that they are not. Parental awareness and influence were most frequently indicated as the basis for preventing EDs, while school and social media were identified as key channels for information about EDs.

CONCLUSIONS: Despite differences between medical and non-medical fields, views and experiences of EDs appear similar, with factors such as age, gender, or year of study potentially being more important. EDs affect women more often and are more widely recognized by them. Given the respondents' interest in EDs and its importance, more effort should be directed toward prevention and the identification of risk factors, especially regarding social media.

KEYWORDS

eating behavior, students' opinions, health attitudes, risk factors, social media

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Address for correspondence: Mateusz Olek, Studenckie Koło Naukowe, Katedra i Zakład Medycyny i Epidemiologii Środowiskowej, Wydział Nauk Medycznych w Zabrzu SUM, ul. Jordana 19, 41-800 Zabrze, tel. +48 32 272 28 47, e-mail: s88309@365.sum.edu.pl



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STRESZCZENIE

WSTĘP: Zaburzenia odżywiania (*eating disorders* – EDs) uważane są za jeden z najbardziej rozpowszechnionych problemów zdrowotnych, charakteryzujący się zróżnicowanym obrazem klinicznym, złożonymi czynnikami ryzyka i konsekwencjami zdrowotnymi. Celem badania było poznanie postaw i opinii studentów kierunków medycznych i niemedycznych z województwa śląskiego na temat EDs.

MATERIAŁ I METODY: Pytania badawcze zostały zadane w formie kwestionariusza internetowego. W badaniu wzięło udział 217 uczestników, a dane analizowano za pomocą programów MS Excel i Statistica.

WYNIKI: Nie zaobserwowano istotnej statystycznie zależności między studentami kierunków medycznych i niemedycznych w zakresie koncentracji na sposobie odżywiania, konieczności zmian żywieniowych czy samooceny wiedzy na temat EDs. Respondenci z wcześniejszych lat studiów wykazywali istotnie większą skłonność do zwracania uwagi na nawyki i sposób odżywiania. Prawie połowa ankietowanych zgłosiła doświadczenie wystąpienia ED; istotnie częściej problem ten dotyczył kobiet. Spośród respondentów 87,6% uznało EDs za istotny problem społeczny i zdrowotny. Większość ankietowanych знаła osoby zmagające się z ED, ale negowała lub nie potrafiła określić, czy osoby takie są wykluczane lub stygmatyzowane. Świadomość i wpływ rodziców były najczęściej wskazywane jako podstawa zapobiegania EDs, natomiast szkoła i media społecznościowe były kluczowymi kanałami informacji o EDs.

WNIOSKI: Pomimo różnic między kierunkami studiów medycznych i niemedycznych poglądy i doświadczenia związane z EDs można uznać za podobne, przy czym czynniki takie jak wiek, płeć czy rok studiów mogą mieć większe znaczenie. Częstość występowania EDs u kobiet jest większa i można przypuszczać, że problem ten jest przez nie szerzej dostrzegany. Biorąc pod uwagę zainteresowanie respondentów EDs oraz ich znaczenie, należy skupić się na profilaktyce i identyfikacji czynników ryzyka, zwłaszcza w kontekście mediów społecznościowych.

SŁOWA KLUCZOWE

zachowania żywieniowe, opinie studentów, postawy zdrowotne, czynniki ryzyka, media społecznościowe

INTRODUCTION

Eating disorders (EDs) represent a serious global issue. In the course of an ED, a harmful eating pattern develops, associated with the number, manner, and frequency of meals, the quality of food, or the related emotions. The habits linked to EDs negatively affect the physical and mental health and impact the daily lives of the individuals affected by these disorders [1]. The International Classification of Diseases (ICD-10) distinguishes types of EDs, such as anorexia nervosa, bulimia nervosa, and other unspecified EDs [1]. EDs were first included in the ICD in 1977 (ICD-9) and were subsequently updated in 1990 in the 10th edition [2].

The highest percentage of individuals struggling with EDs is observed in the 15–19 age group, often with a significantly higher proportion in females than in males [3]. However, it is worth noting that young adults are a vulnerable population. Of particular concern is the increasing proportion of children under 12 seeking treatment for EDs, especially girls. Anorexia and bulimia nervosa are significantly more common in females than in males. Interestingly, binge eating disorder is more frequently diagnosed in males [1].

Anorexia nervosa is characterized by intentional weight loss, which is consciously induced and maintained by the individual [4]. A distorted body image is also present [1]. Patients maintain a low body weight through various behaviors, such as excessive physical activity, self-induced vomiting, or the use of pharmacological agents [4]. In contrast, bulimia nervosa involves episodes of binge eating, during

which individuals consume a large amount of food in a short period and afterward engage in compensatory behavior to reduce the effects. Unlike bulimia, patients with binge eating disorder do not engage in compensatory behavior after binge episodes [1].

The risk of developing an ED is influenced by numerous factors. Most commonly, individual, biological, sociocultural, and familial factors have been identified [4]. The diagnosis of EDs is based on an assessment of the patient's body weight. For individuals under 15 years of age, appropriate percentile charts are used, while for those over 15, the severity of the disorder is assessed according to their body mass index (BMI) [1].

The treatment of EDs is a complex, long-term process that requires consistency. Therapeutic intervention addresses both somatic and psychological symptoms and necessitates an individualized approach for each patient. Failure to undergo treatment leads to a worsening of the condition and is associated with serious health consequences. In extreme cases, it can result in severe physical deterioration or even death [1].

The aim of the study was to examine the attitudes and opinions of medical and non-medical students from the Silesian Voivodeship towards the issue of ED.

MATERIAL AND METHODS

The study was conducted between February and April 2025. Following approval from the Bioethics Committee, an anonymous online survey (Google Forms) was used and distributed among students from universities located in the Silesian Voivodeship,



regardless of the type of institution, field of study, year, or mode of study. A total of 252 complete responses were collected. Finally, 217 responses were included in the analysis following the application of the exclusion criteria: responses from outside the Silesian Voivodeship and those from individuals outside the 18–26 age range (typical for the student population).

The original questionnaire consisted of 38 closed (single- and multiple-choice) and open-ended questions. It was divided into four sections concerning demographic data, general knowledge about EDs, the role of social media in the context of EDs, and the experiences, opinions, and attitudes toward this issue. The data were analyzed using Microsoft Excel and Statistica v. 13.3 (StatSoft, Poland). Associations were assessed using the chi-square test (Pearson's and maximum likelihood), with a significance level of $p < 0.05$.

RESULTS

A total of 217 individuals participated in the study, of whom 67.3% ($n = 146$) were students of medical disciplines, while 32.7% ($n = 71$) were students of non-medical disciplines. The participants' ages ranged from 18 to 26 years (mean age: 21.3 ± 1.8).

The participants were associated with the following universities: Medical University of Silesia in Katowice (61.3% [$n = 133$]), University of Silesia in Katowice (11.1% [$n = 24$]), Jan Długosz University in Częstochowa (6.5% [$n = 14$]), Jerzy Kukuczka Academy of Physical Education in Katowice (6.5% [$n = 14$]), University of Economics in Katowice (4.1% [$n = 9$]), WSB Merito Universities (3.7% [$n = 8$]), Wojciech Korfańty Upper Silesian Academy in Katowice (2.8% [$n = 6$]), Silesian University of Technology (1.8% [$n = 4$]), University of Bielsko-Biala (1.8% [$n = 4$]), and Karol Szymanowski Academy of Music in Katowice (0.5% [$n = 1$]).

Table I presents the distribution of the respondents' fields of study into medical and non-medical categories, along with the number and percentage of responses for each major. The highest rate of responses was obtained among medical students, specifically those studying medicine (36.9% [$n = 80$]). Among non-medical disciplines, the largest group consisted of pedagogy students (6.5% [$n = 14$]).

Table I. Characteristics of the study group ($N = 217$) by field of study. Medical fields are marked in red

Field of study	N (%)
Medicine	80 (36.87)
Dentistry	43 (19.82)
Pedagogy	14 (6.45)
Emergency medical services	9 (4.15)
Tourism and recreation	9 (4.15)
Management	8 (3.69)
Psychology	7 (3.23)
Nursing	6 (2.76)
Physical therapy	6 (2.76)
International studies in political science and diplomacy	4 (1.84)
Urban economy and real estate	3 (1.38)
Computer science	3 (1.38)
German philology	3 (1.38)
Art education	2 (0.92)
Business logistics	2 (0.92)
Finance and accounting	2 (0.92)
National security	2 (0.92)
Dietetics	1 (0.46)
Pharmacy	1 (0.46)
Music therapy	1 (0.46)
Graphic design	1 (0.46)
Cognitive technologies and social media	1 (0.46)
Cultural studies	1 (0.46)
Polish studies	1 (0.46)
Applied linguistics	1 (0.46)
English philology	1 (0.46)
Italian philology	1 (0.46)
Chemical technology	1 (0.46)
Mechanical engineering	1 (0.46)
Architecture	1 (0.46)
Mathematics	1 (0.46)
Total	217 (100)

The majority of the students were in their second (34.1% [$n = 74$]) or first (29.5% [$n = 64$]) year of study. Women accounted for 82.9% ($n = 180$) of the study group, men for 15.7% ($n = 34$), while



2 respondents (0.9%) identified as another gender, and 1 person (0.5%) chose not to disclose their gender. The most common place of residence was a city with a population between 150,000 and 500,000 (26.7% [n = 58]), while the least common was a city with over

500,000 inhabitants (8.3% [n = 18]). Figure 1 presents the characteristics of the study group in terms of gender, year of study, and place of residence, with a breakdown by medical and non-medical fields of study.

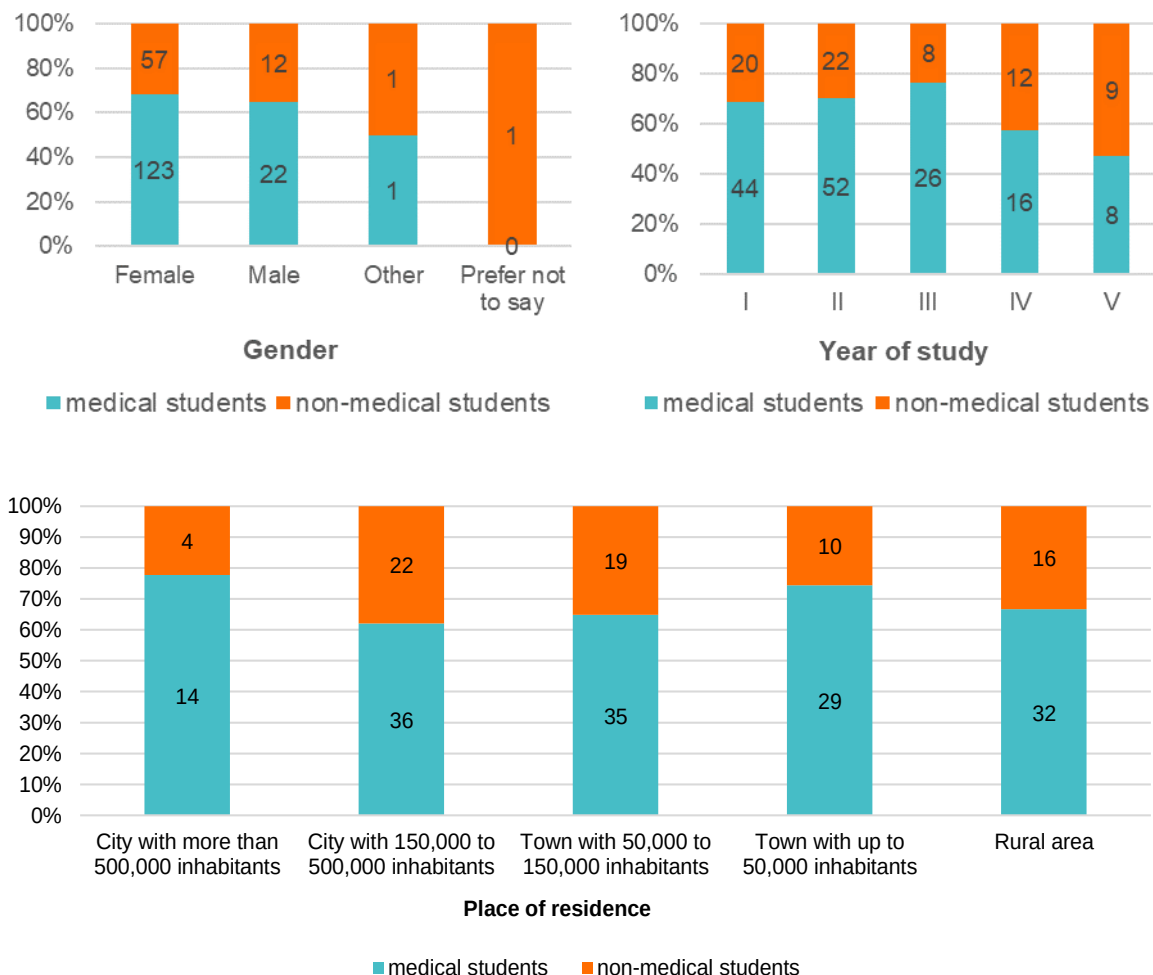


Fig. 1. Characteristics of the study group (N = 217) by gender, year of study, and place of residence.

The majority of respondents (68.2% [n = 148]) indicated the need to introduce changes to their eating habits (Figure 2). Similarly, most students declared that they had knowledge about EDs; the self-assessed levels of knowledge are presented in Figure 2. Only 2.8% (n = 6) of the participants rated their knowledge as low or very low and only 1.4% (n = 3) were unable to assess it. No statistically significant differences were found between medical and non-medical students regarding the need to implement

dietary changes ($p > 0.05$) or their self-assessment of knowledge about EDs ($p > 0.05$).

No statistically significant association was observed between medical and non-medical students in terms of their focus on eating habits ($p > 0.05$). A significant relationship was found between the year of study and conscious eating behavior ($p < 0.05$), with respondents in the earlier years (I–II) showing a particular tendency to pay attention to their habits and dietary choices (Figure 3).

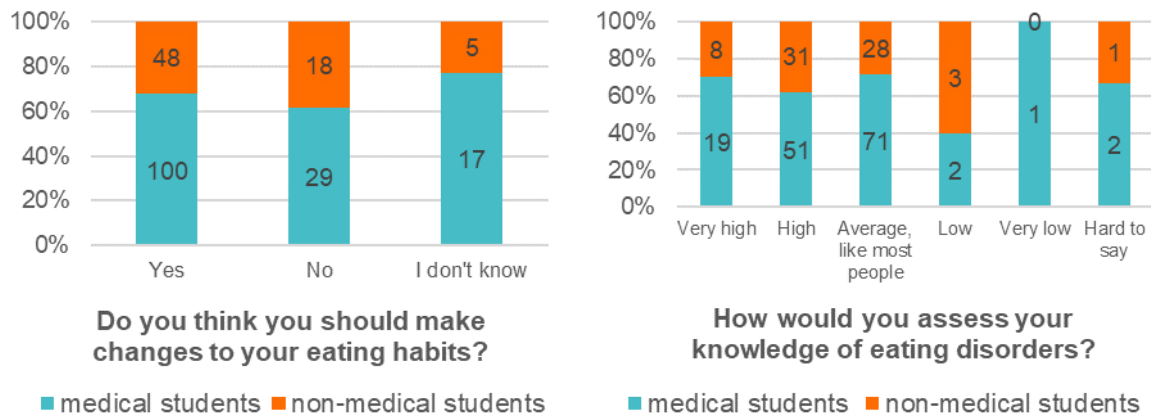


Fig. 2. The need for dietary changes ($p > 0.05$) and self-assessed knowledge of eating disorders among medical ($n = 146$) and non-medical students ($n = 71$) ($p > 0.05$).

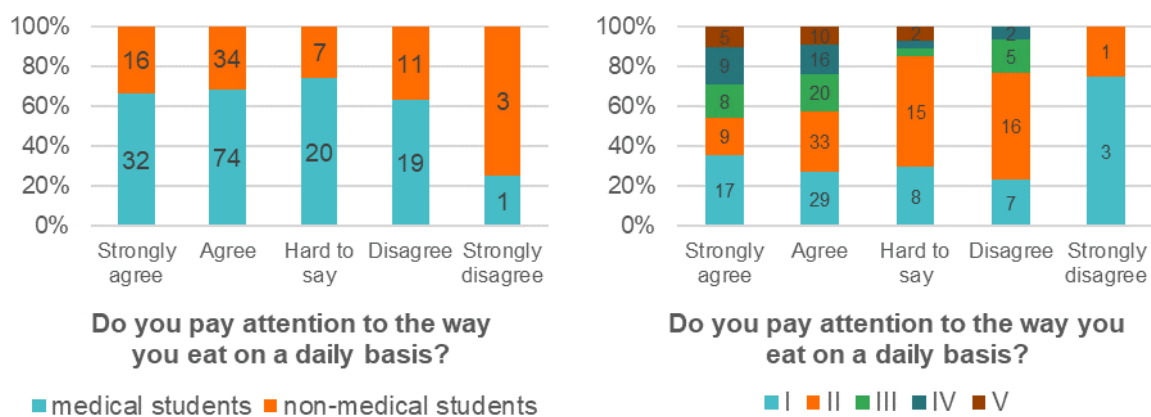


Fig. 3. Perceived attention to eating habits among medical ($n = 146$) and non-medical students ($n = 71$) ($p > 0.05$) and year of study ($p = 0.01$).

Almost half of the respondents (47.5% [$n = 103$]) reported experiences of struggling with an ED. Among the female participants, 51.1% ($n = 92$) confirmed having such experiences, whereas the majority of the male respondents (61.8% [$n = 21$]) denied having any EDs. This issue was significantly more common among women ($p < 0.05$). The results regarding experiences with EDs are shown in Figure 4.

The majority of respondents (72.4% [$n = 157$]) knew of others who had struggled with EDs; another 15.7%

($n = 34$) indicated that they did not know anyone, and 12.0% ($n = 26$) answered “I don’t know.” Overall, 41.9% ($n = 91$) of the participants denied or strongly denied that such individuals are socially excluded or stigmatized, while 35.0% ($n = 76$) were unable to say. Additionally, 87.6% ($n = 190$) of respondents recognized EDs as a significant social and health issue (Figure 5). No statistically significant differences were observed between medical and non-medical students in the assessment of the importance of this problem ($p > 0.05$).

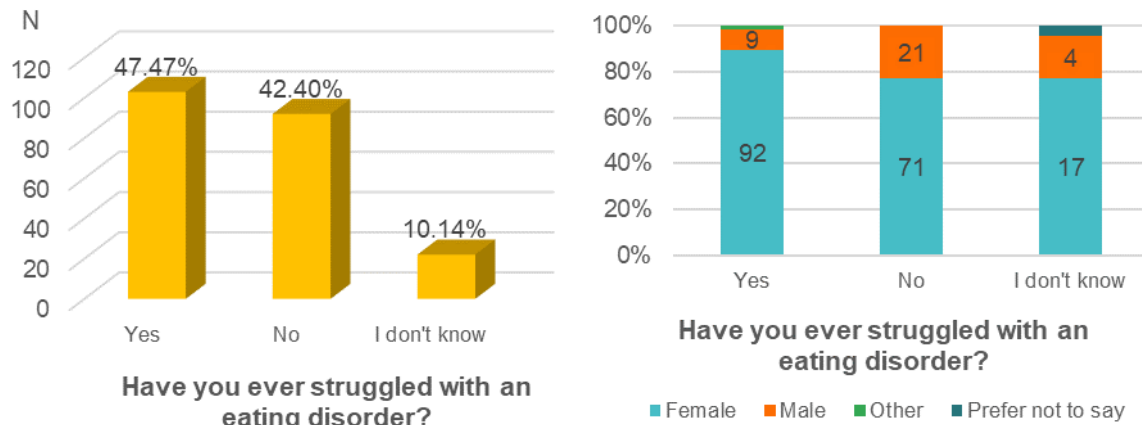


Fig. 4. Prevalence of eating disorders among the respondents (N = 217) and its association with gender (p = 0.006).

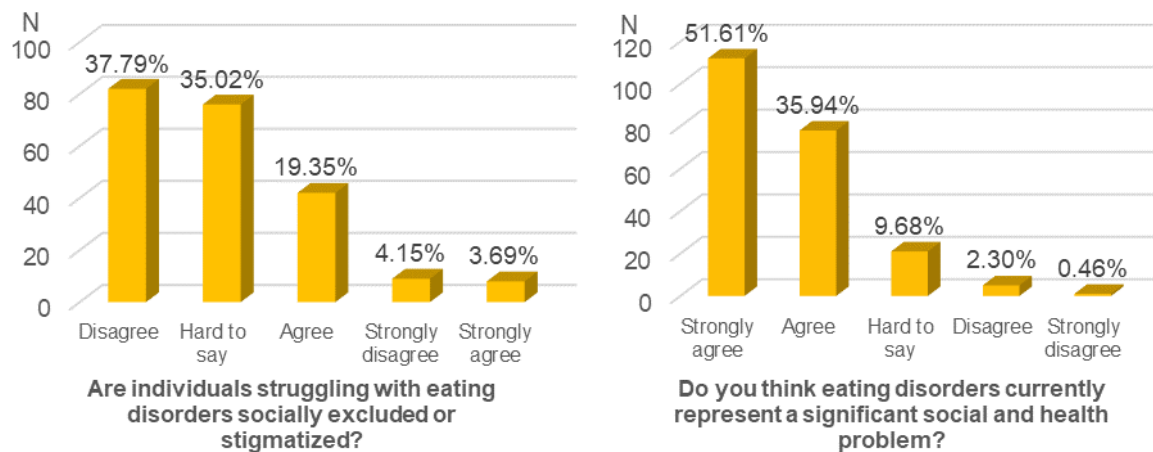


Fig. 5. Respondents' perceptions of the stigmatization of eating disorders in society and of the importance of eating disorders (N = 217).

Figure 6 presents the respondents' opinions on channels for preventing and communicating about EDs. The most frequently indicated means of prevention were parents' awareness and positive influence on their child (95.9% [n = 208]) as well as nutritional education (88.0% [n = 191]). As for channels of communication for ED-related content,

the majority selected school (94.9% [n = 206]) and social media (89.4% [n = 194]). As many as 92.2% (n = 200) of the respondents had encountered content related to EDs on social media. Furthermore, 63.6% (n = 138) strongly agreed and 28.6% (n = 62) agreed that social media can increase the risk of developing EDs (Figure 7).

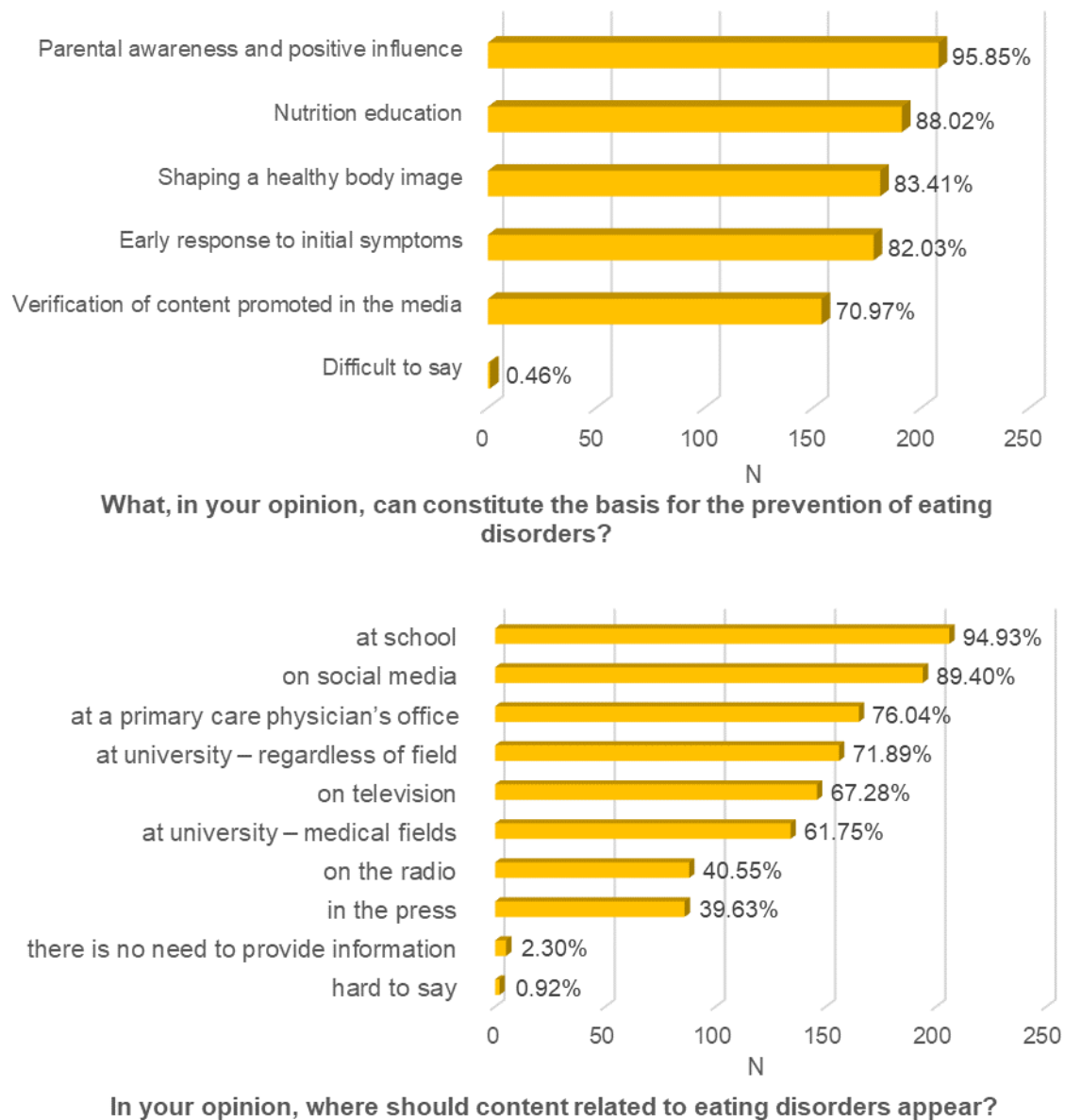


Fig. 6. Means of preventing and communicating information about eating disorders according to the respondents (N = 217).

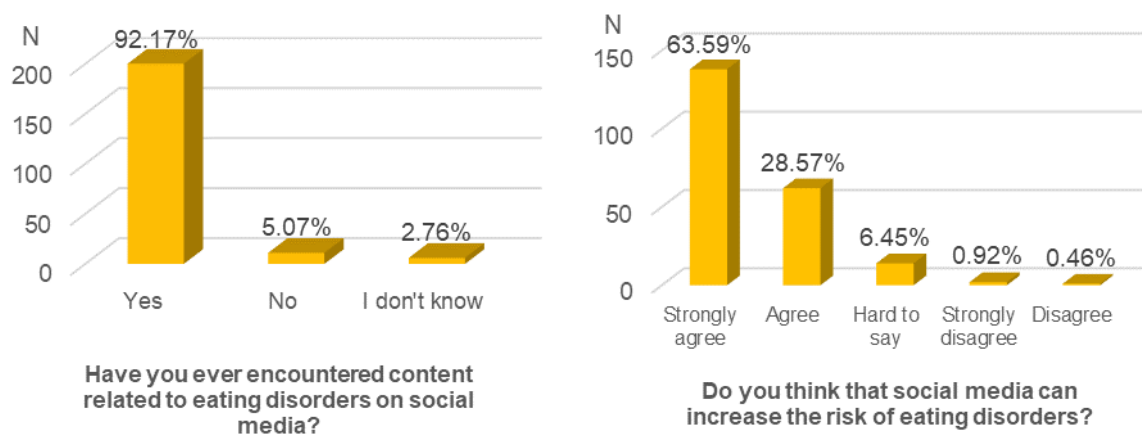


Fig. 7. Perceived presence of eating disorder-related content and the impact of social media on the risk of developing eating disorders, according to the respondents (N = 217).



DISCUSSION

EDs are recognized as a significant health challenge, both in Poland and worldwide. Over the past decade, the global prevalence of EDs has more than doubled, increasing from an estimated 3.5% to 7.8%. Approximately 40% of cases involve adolescents aged 15–19 years [1,3].

The study, based on the opinions of students from both medical and non-medical fields, demonstrated that awareness of the issue exists, regardless of whether the individual is studying a field directly related to health and medicine. Moreover, when asked to assess their level of knowledge about EDs, only 2.8% of the respondents considered it low, and just 1.4% were unable to assess it. No significant difference was found between medical and non-medical students in this regard. This lack of association is noteworthy, given the greater exposure of medical students to topics related to EDs, their contact with patients, and potentially greater knowledge and experience in these areas compared to non-medical students. Another study conducted on minor patients reported no refusals to participate due to a lack of knowledge about EDs [5]. It was noted that patients admitted for an ED be more knowledgeable on the subject than those without similar experiences. Comparing the two studies, it is important to highlight that in the group of university students examined here, 47.5% declared that they had struggled with an ED in the past.

Only 23.0% of respondents stated that individuals with EDs are socially excluded or stigmatized. Other studies have examined the stigma toward people suffering from EDs in greater depth [6,7]. These studies found that the overall stigmatization is low to moderate, though certain areas require particular attention, such as stigma related to personal responsibility. The authors emphasize the need for continued efforts to combat stigma.

Social media were identified by respondents as one of the factors promoting EDs. However, when asked where content about EDs should be disseminated, it was indicated as the second most important channel after school. This suggests an awareness of both the dangers posed by social media and their potential benefits in preventing EDs. Moreover, 71.0% of the respondents believed that one form of ED prevention could be verifying the content promoted on social media. A study of Norwegian adolescents described the impact of social media on EDs as negative, although the researchers highlighted the high proportion of responses that social media have a positive influence on body image perception [8].

Given the ever-increasing role and influence of social media in daily life, further evaluation of their impact on society is necessary [7,8]. Particular attention should be paid to short-form videos, such as TikTok, YouTube Shorts, and Instagram Reels, which are currently widely viewed by younger audiences and older viewers. Additionally, it is worth emphasizing the declining importance of traditional media such as radio and print press, which were least frequently indicated by the respondents as channels for preventing and raising awareness of EDs.

The main limitation of the study was the low representation of men. This is most likely due to women showing a greater interest in the topic of EDs, which may indicate their higher sensitivity caused by the higher overall occurrence of EDs among women, especially at ages similar to those of the participants. The majority of the participants (72.4%) indicated that they knew someone who had struggled with an ED. Moreover, 51.1% of the female respondents declared having a personal experience with EDs, in contrast to 38.2% of the male respondents. In other studies, considerably fewer individuals admitted to having experienced EDs in the past, with 8.32% [6] and 11.56% [7] reporting a history of EDs and only 2.51% [6] and 3.85% [7] currently struggling with an ED. The issue of men being underrepresented in study groups also appeared in study by Lupo et al. [6], conducted among Italian nursing students, which reported a gender distribution of 74.47% women versus 25.53% men. A similar problem was noted in study by Caslini et al. [7], with 80.93% women versus 19.07% men. Difficulties in recognizing EDs in boys and young men should also be considered. In adolescent girls or young women, a common early warning sign for parents may be the cessation of menstruation due to inadequate nutrition. For males, a suspected ED is often indicated by less specific observations, such as BMI or triceps skinfold thickness measurements [9]. Cultural factors should not be neglected, as they may discourage men from seeking help or lead to EDs being associated primarily with women. The limited number of men in such studies suggests that EDs in boys and men remains insufficiently researched, highlighting the need for further investigation in this area.

An additional limitation of the study is the imbalance in the number of students from medical and non-medical fields. Gathering opinions from a larger number of students, especially those outside the medical sciences, could provide further insights. The higher level of engagement among medical students can be explained by the study's subject matter aligning with their field of education and interests related to health and medicine.



CONCLUSIONS

Despite differences between medical and non-medical fields of study, the opinions, attitudes, and experiences related to EDs were similar. Other factors, such as age, gender, or year of study, may have had a greater significance. Considering the high level of interest in the subject and the frequency of EDs among women, it can be assumed that this issue is more widely

recognized by them and may be regarded as a significant aspect of their health. Given the respondents' interest in ED-related content on social media, the role of these platforms should be considered both a risk factor and a potential tool for education or support. EDs currently represent a significant social and health challenge, as confirmed by the respondents' opinions. Therefore, further research in this area is necessary, particularly regarding the identification of risk factors and preventive measures.

Author's contribution

Study design – M. Olek, K. Lau

Data collection – M. Ordowski, J. Klag

Data interpretation – M. Olek, M. Ordowski, K. Lau

Statistical analysis – M. Olek, M. Ordowski

Manuscript preparation – M. Olek, M. Ordowski, J. Klag, K. Lau

Literature research – M. Olek, M. Ordowski, J. Klag

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***Corynebacterium diphtheriae* – An underrated threat? An analysis of the epidemiological risk of diphtheria in the 21st century**

Corynebacterium diphtheriae – niedoceniane zagrożenie?
Analiza ryzyka epidemiologicznego błonicy w XXI wieku

Magdalena Sulasz¹, Jakub Fiegler-Rudol¹ , Karolina Lau² , Janusz Kasperczyk²

¹Students' Scientific Club, Department of Environmental Medicine and Epidemiology, Faculty of Medical Sciences in Zabrze,
Medical University of Silesia, Katowice, Poland

²Department of Environmental Medicine and Epidemiology, Faculty of Medical Sciences in Zabrze,
Medical University of Silesia, Katowice, Poland

ABSTRACT

Diphtheria is a potentially severe infectious disease caused by *Corynebacterium diphtheriae*, whose primary pathogenic factor is diphtheria toxin. Despite a significant reduction in incidence due to vaccination, recent years have seen a resurgence of cases, indicating a persistent epidemiological threat. The aim of this study is to present the current status of diphtheria as an epidemiological threat and to assess whether, in light of contemporary medical knowledge and current vaccination statistics, the threat remains significant both in Poland and globally. A narrative review of the literature from 2000 to 2024 was conducted using the PubMed, Scopus and Google Scholar databases, as well as WHO and CDC documents. Scientific, clinical, and epidemiological data were analyzed for their relevance and utility for public health. Diphtheria still poses a risk of serious cardiac and neurological complications, particularly in populations with reduced herd immunity. Effective prevention requires early diagnosis, rapid treatment (antitoxin and antibiotic therapy), and high vaccination coverage. Although diphtheria is now rare, it should not be underestimated. Educational, preventive, and epidemiological efforts are essential to prevent its resurgence. Vaccination remains the most effective form of protection.

KEYWORDS

Corynebacterium diphtheriae, diphtheria toxin, vaccination, epidemiology, prevention, antitoxin

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Address for correspondence: Magdalena Sulasz, Studenckie Koło Naukowe, Katedra i Zakład Medycyny i Epidemiologii Środowiskowej, Wydział Nauk Medycznych w Zabrzu SUM, ul. Jordana 19, 41-808 Zabrze, tel. +48 32 272 28 47, e-mail: s91778@365.sum.edu.pl



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STRESZCZENIE

Błonica (dyfteryt) to potencjalnie ciężka choroba zakaźna wywoływana przez *Corynebacterium diphtheriae*, której głównym czynnikiem chorobotwórczym jest toksyna błonicza. W ostatnich latach, mimo znacznego ograniczenia liczby zachorowań dzięki szczepieniom ochronnym, obserwuje się ponowny wzrost liczby przypadków, co wskazuje na utrzymujące się zagrożenie epidemiologiczne. Celem pracy jest przedstawienie aktualnego stanu zagrożenia epidemiologicznego błonicą oraz ocena, czy w świetle współczesnej wiedzy medycznej i aktualnych statystyk dotyczących szczepień zagrożenie to pozostaje istotne zarówno w Polsce, jak i na świecie. Przeprowadzono przegląd narracyjny literatury z lat 2000–2024, korzystając z baz PubMed, Scopus i Google Scholar, a także dokumentów WHO i CDC. Analizie poddano dane naukowe, kliniczne i epidemiologiczne pod kątem ich znaczenia i przydatności dla zdrowia publicznego. Błonica nadal niesie ryzyko poważnych powikłań kardiologicznych i neurologicznych, zwłaszcza w populacjach z obniżoną odpornością zbiorowiskową. Skuteczna profilaktyka wymaga wczesnej diagnostyki, szybkiego leczenia (antytoksyna i antybiotykoterapia) oraz wysokiego poziomu wyszczepienia. Choć obecnie błonica występuje rzadziej, nie należy jej lekceważyć. Działania edukacyjne, profilaktyczne i epidemiologiczne są niezbędne, by zapobiec jej nawrotom. Szczepienia pozostają najskuteczniejszą formą ochrony.

SŁOWA KLUCZOWE

Corynebacterium diphtheriae, toksyna błonicza, szczepienia, epidemiologia, profilaktyka, antytoksyna

INTRODUCTION

Diphtheria (also known as diphtheritis or croup) is caused by an unencapsulated, non-motile, aerobic, Gram-positive bacillus *Corynebacterium diphtheriae* (*C. diphtheriae*; *diphtheria bacillus*) [1]. The disease may be asymptomatic, but often affects the respiratory and cutaneous systems, and can also lead to complications involving other organ systems [2]. The main risk factor for infection is remaining unvaccinated. Transmission occurs primarily via respiratory droplets. The pathogenicity of the bacterium depends on its ability to produce exotoxins that can spread through the bloodstream and cause damage to the myocardium and nervous system [1,2,3]. Patients infected with *C. diphtheriae* typically present with a characteristic thick, grey pseudomembrane adhering to the tonsils and pharynx. Immunization against diphtheria is part of the routine vaccination schedule, administered as a component of the combined diphtheria, tetanus, and pertussis (DTP) vaccine [3,4,5]. Due to widespread immunization, the global number of cases significantly decreased from approximately 98,000 in 1980 to around 4,200 in 2010. However, a recent increase in cases has been observed, suggesting that diphtheria remains an epidemiological challenge [1,2,3,4,5].

The aim of this study is to explore why *C. diphtheriae* still constitutes an epidemiological threat and to determine whether this threat remains relevant in Poland and worldwide, considering current scientific knowledge.

Methods

This study employed a narrative literature review to comprehensively discuss the epidemiological threat posed by *Corynebacterium diphtheriae* and to assess the current state of knowledge regarding diphtheria in Poland and globally. The objective was to collect,

analyze, and synthesize data from various scientific, clinical, and epidemiological sources related to the etiology, pathophysiology, clinical symptoms, diagnostics, treatment, and prevention of diphtheria. Materials were collected by searching scientific databases including PubMed, Scopus, and Google Scholar. The review encompassed scientific publications, review articles, clinical guidelines, and official epidemiological reports published between 2000 and 2024, with particular emphasis on the most recent decade. The inclusion criteria called for publications in Polish or English addressing the clinical course of diphtheria, articles discussing its diagnosis, treatment, and prevention, clinical guidelines for the management of diphtheria cases, and peer-reviewed works or documents issued by recognized medical and public health institutions. The exclusion criteria applied to publications without clinical data, such as purely laboratory or molecular studies without clinical relevance, popular-science and non-peer-reviewed articles, local or historical papers without current relevance to healthcare, texts in languages other than Polish or English, and duplicates or conference abstracts without full data. Additionally, historical and classical medical sources were reviewed to present the development of knowledge about diphtheria over time. The information was subjected to qualitative analysis, with attention to data currency, consistency with current guidelines, and relevance in both epidemiological and clinical contexts.

Historical background

The first references to a disease resembling diphtheria can be traced back to Hippocrates (circa 300 BCE). A more comprehensive description was later provided by Aretaeus of Cappadocia (1st century CE), who described pseudomembranes on the tonsils and respiratory distress, among other features [6]. In 1821, Bretonneau was the first to use the term “diphtheria”, and in 1883–1884, Klebs and Löffler discovered and



isolated its etiological agent, *Corynebacterium diphtheriae* (also known as the Klebs–Löffler bacillus). By the end of the 19th century, diphtheria posed a significant threat, including to medical personnel [6]. A major breakthrough in treatment occurred with the introduction of an equine antitoxin by von Behring in 1890. In 1924, an effective vaccine based on the diphtheria toxoid (PW8) was developed, leading to vaccination programs and a substantial reduction in the number of cases [7,8,9].

MICROBIOLOGICAL CHARACTERISTICS OF *C. diphtheriae*

C. diphtheriae is a Gram-positive, non-motile, non-encapsulated bacillus with a characteristic club-shaped morphology, often arranging in V- or L-shaped formations. The bacterium does not form spores. In addition to *C. diphtheriae*, cutaneous diphtheria can also be caused by *C. ulcerans* [1]. Four main biotypes of *C. diphtheriae* are distinguished – gravis, mitis, intermedius, and belfanti – all of which can produce diphtheria toxin [1,10,11,12,13,14]. The toxigenicity of the bacterium depends on the presence of a bacteriophage carrying the *tox* gene. The toxin consists of two fragments: B, which is responsible for binding to the host cell, and A, which inactivates elongation factor EF-2, thereby blocking protein synthesis and leading to cell death [1,5,7]. The result of the toxin's action is tissue necrosis, along with the characteristic pseudomembranes in the upper respiratory tract; damage may also extend to the myocardium, kidneys, and nervous system [3,15].

ROUTES OF TRANSMISSION AND RISK FACTORS

C. diphtheriae is primarily transmitted via exhaled droplets, for example, through coughing, but also through contact with the secretions of infected individuals, skin lesions, or contaminated objects [16]. Infection may also arise from close contact with animals that serve as reservoirs of the bacterium [17]. Medical risk factors include insufficient vaccination, immunosuppression, and low herd immunity levels. Non-medical risk factors include traveling to endemic regions, low socioeconomic status, living in overcrowded conditions (e.g., in prisons or shelters), and mass migration. Diphtheria infection does not correlate with gender or ethnicity, although it most commonly affects children under 12 years of age [1]. Adults are also susceptible, particularly those who have not received booster doses of the vaccine. The incubation period typically ranges from 2 to 5 days. The infectious period lasts throughout the

clinical course of the disease and may continue for 2 to 3 weeks after symptoms resolve [6]. Asymptomatic carriers also constitute a significant source of infection, as they may unknowingly transmit the bacterium, especially in populations with low vaccination coverage [18,19,20,21,22,23,24].

CLINICAL PRESENTATION, DIAGNOSIS, AND TREATMENT OF DIPHTHERIA

Diphtheria typically develops within 2 to 5 days of infection. Symptoms include fever, sore throat, difficulty breathing and swallowing, cervical lymphadenopathy, and the presence of a characteristic grey, fibrous pseudomembrane in the throat. Advanced cases may lead to the development of so-called “bull neck,” dyspnea, hoarseness, and signs known as “diphtheritic croup” [13,19]. Nasal diphtheria is characterized by a chronic, often bloody discharge and mild systemic symptoms [13]. The cutaneous form most commonly affects the legs and manifests as non-healing ulcers covered with a grey membrane, especially in areas of previous skin injury [25,26,27,28].

Complications result from the action of diphtheria toxin, which may damage the heart and nervous system. Myocarditis occurs in most severely ill patients and can present as heart failure, arrhythmias, electrocardiographic abnormalities, and even death during convalescence [4,7]. Neuropathies typically affect the soft palate, extraocular muscles, and cranial nerves, with limb paralysis occurring in later stages [29,30,31,32,33,34,35].

Diagnosis is based on clinical presentation, patient history (vaccination status, travels, and contact), and microbiological testing and is confirmed by the Elek test, PCR, or EIA for detecting the *tox* gene, as well as cultures on specialized media such as Loeffler or Tindale agar [1,7,11]. Differential diagnosis should consider other pharyngeal diseases, including streptococcal pharyngitis, infectious mononucleosis, epiglottitis, oral candidiasis, and retropharyngeal abscess [1,9,10].

Treatment includes administration of diphtheria antitoxin (DAT) and antibiotic therapy (erythromycin or penicillin G) and must be initiated as early as possible. The antitoxin only neutralizes circulating toxin, so its effectiveness depends on the timing of administration – delays significantly increase mortality [12,13,35,36,37,38,39,40]. Antibiotics shorten the period of infectivity and eradicate the bacteria, with alternatives such as linezolid or metronidazole being available in cases of resistance [1,14]. Patients should be isolated for at least 6 days or until two consecutive negative culture results are obtained [12]. The increasing antibiotic resistance of



C. diphtheriae, observed in Brazil, for example, highlights the need for continuous surveillance and therapy adjustment [41,42,43,44,45].

Early diagnosis and prompt treatment are crucial for prognosis. The highest mortality rates are observed in children under the age of 5 and adults over 40, as well as in cases with delayed treatment and cardiovascular involvement [1].

CONTEMPORARY EPIDEMIOLOGY AND GLOBAL SITUATION

Following the introduction of widespread DTP vaccination, there was a dramatic global decline in diphtheria cases. In the 1980s, nearly 100,000 cases were still being reported annually; for example, there were over 97,000 in 1980 alone [27]. The incidence significantly decreased over the following decade. However, in the mid-1990s, a serious diphtheria epidemic occurred in the countries of the former Soviet Union, resulting in over 150,000 reported cases and approximately 5,000 deaths. This outbreak demonstrated that large adult populations with no immunity and low childhood vaccination rates can lead to a rapid resurgence of the disease within communities. Thanks to international control efforts, including catch-up vaccination campaigns, the epidemic was contained by the late 1990s. Global incidence reached its lowest levels in the early 2000s. In subsequent years, the incidence remained relatively low, with annual global reports ranging from several thousand to just over ten thousand cases [28,32,46,47].

However, since around 2010, a renewed increase in global diphtheria cases has been observed. In the last decade, the number of reported cases has nearly quintupled (between 2010 and 2019) [27]. For example, in 2017, there were 8,819 reported cases – the highest since 2004 – and by 2019, the global figure exceeded 22,000 [27,28]. It is important to note that these numbers are based on WHO/UNICEF surveillance reports and are likely underestimated, meaning that the actual number of cases may be significantly higher. The rise in cases from 2010 to 2020 has been attributed not only to improved surveillance and case detection (particularly in endemic countries), but also to the emergence of outbreaks under specific conditions, such as armed conflicts, mass migrations, and a decline in vaccine confidence in certain populations. Despite the overall downward trend observed since the 1960s, diphtheria remains a significant public health concern on a global scale [28].

Epidemiological situation in different countries worldwide

The epidemiological situation of diphtheria varies significantly across regions. Currently, the disease remains endemic primarily in the developing countries of Asia and Africa. The highest numbers of cases are reported in Southeast Asia and Africa [27,29,30,46,47,48,49,50,51]. In contrast, in the Americas, diphtheria has been largely eliminated except in countries such as Haiti and the Dominican Republic, where outbreaks continue to occur [30]. In Europe, thanks to widespread vaccination, the situation remained stable for many years, with only a few dozen cases being reported annually [31]. However, even in these regions, diphtheria can resurge locally under favorable conditions.

There is a clear difference in epidemiological patterns between developed and developing countries. In high-income countries with organized immunization programs, diphtheria has largely faded from public awareness. In most countries of Western Europe, the disease is usually imported by travelers or migrants from endemic regions or is spread among unvaccinated subpopulations. Thanks to high vaccination coverage, the disease does not spread widely in these societies. According to available data, diphtheria is rare in high-income countries [27]. For instance, in the United States, respiratory diphtheria has been virtually absent over the past two decades, with the last case being reported in 2003, involving an American traveler [30]. In the European Union (EU), before 2022, an average of around 50 cases were reported annually (mostly isolated incidents), which, given the population of over 500 million, indicated near-elimination. A rise was observed in 2022–2023, when 281 cases were reported in Europe, mainly among migrants in reception centers. These cases largely involved individuals from endemic regions, including outbreaks in refugee facilities in Germany and Switzerland. However, no broader transmission to the general European population was recorded. This incident demonstrates that even developed countries must maintain epidemiological vigilance, because migration and travel can reintroduce diphtheria into local communities, but also that high vaccination rates prevent wider spread [32].

Diphtheria remains endemic in low- and middle-income countries and periodic epidemics are a major public health concern. Low primary DTP vaccination rates and limited access to healthcare allow the bacterium to continue circulating, particularly in densely populated, impoverished areas [27]. Most



global diphtheria cases originate from developing countries. According to the World Health Organization (WHO), nearly all reported infections occur in Asia, Africa, and parts of the Americas. For example, India has reported thousands of cases annually for many years, accounting for a significant share of the global burden. Indonesia experienced recurring outbreaks in the past decade, with over 4,000 pediatric cases being reported in East Java province alone since 2011 [29]. Bangladesh faced a major outbreak among Rohingya refugees living in unsanitary conditions in 2017–2018. Yemen saw thousands of cases across several provinces during its ongoing civil war (2017–2018), driven by the collapse of vaccination and healthcare systems. Venezuela, affected by economic crisis, also experienced a diphtheria resurgence, with thousands of cases being reported since 2016 due to declining immunization rates and emigrating medical professionals [27]. Other examples include Pakistan and Nepal (outbreaks after 2010), Haiti (epidemic following natural disasters), and Ukraine, where dozens of cases were reported in 2017–2018 amid declining vaccine confidence [30]. These examples underscore that developing countries frequently struggle with diphtheria outbreaks, especially where underfunded health systems, conflict, and migration converge [27].

Factors contributing to diphtheria outbreaks

Despite the availability of an effective vaccine, *C. diphtheriae* can still cause local outbreaks when favorable conditions arise. One major factor is war and armed conflict. During wars, routine healthcare services and immunization programs collapse and civilians are often exposed to overcrowded shelters and poor hygiene. This creates an ideal environment for diphtheria transmission. Notable examples include the outbreak in Yemen (2017–2018) and clusters in Syria during the civil war. In such contexts, the lack of routine vaccinations and limited access to treatment, including DAT, often results in high mortality. The WHO emphasizes that diphtheria is particularly likely to re-emerge in settings of conflict or political instability, where overcrowding, interrupted vaccination schedules, and collapsed health infrastructure intersect [27].

Another major contributor is migration and population displacement. Mass population movements can introduce pathogens from endemic areas into regions where diphtheria has not been reported for years. This is especially true for refugees and migrants from countries with low vaccination coverage. Displacement camps with poor living conditions are prone to outbreaks, such as the diphtheria epidemic among Rohingya refugees in Bangladesh [27]. Even

small-scale movements, such as air travel by infected individuals, can lead to more cases. Europe faced this challenge in 2022, when most newly reported cases involved migrants in reception centers [32].

Low vaccination coverage and immunity gaps also increase the risk of outbreaks. Communities with insufficient diphtheria vaccination rates are vulnerable, particularly where large proportions of children or adults remain unvaccinated or lack immunity. The post-Soviet epidemic illustrated how a significant group of unprotected adults, combined with disrupted childhood vaccination programs, created ideal conditions for the rapid spread of disease [28]. Today, countries where coverage with a third dose of the DTP vaccine (DTP3) remains below the recommended 90% threshold frequently experience outbreaks. According to WHO estimates, in 2021, approximately 14.5 million infants worldwide did not receive even the first dose of DTP due to limited access or vaccine hesitancy. This “zero-dose” population represents a key reservoir for potential infection [33]. Pockets of incomplete vaccination are found in all countries, including high-income ones, highlighting the importance of achieving and maintaining high vaccination coverage across all population groups [27].

Weak and underfunded healthcare systems also play a critical role. Inadequate infrastructure and disrupted preventive programs facilitate the resurgence of infectious diseases. Inadequate epidemiological surveillance means that outbreaks may go undetected until they escalate. A specific issue in diphtheria management is the limited global supply of diphtheria antitoxin, with ongoing shortages complicating outbreak response [29].

In a world where *C. diphtheriae* still circulates in some populations, it is crucial to identify the most vulnerable groups. The highest-risk group includes unvaccinated or incompletely vaccinated individuals, particularly children who have not completed the full DTP series. The absence of vaccine-induced immunity means that even occasional contact with the pathogen can lead to disease. During outbreaks, most cases occur among unvaccinated individuals – for instance, during one outbreak in Indonesia, 76% of affected children had not completed DTP immunization [29]. However, diphtheria can affect any age group if immunity is lacking. Communities that refuse vaccination (due to religious or ideological reasons) often form clusters of susceptible individuals [30].

Another at-risk group is adults who have not received recent booster doses. Because vaccine-induced immunity against diphtheria wanes over time, booster doses are recommended every 10 years [31]. Adults who have not received a booster in the past decade may



have insufficient antibody levels. In the United States, in 2017, only 63.4% of adults reported having received a tetanus-diphtheria (Td) vaccine within the last 10 years and only 31.7% had received the Tdap vaccine, which also protects against pertussis [44]. This includes elderly individuals vaccinated long ago or exposed to diphtheria in childhood, whose immunity may have diminished over time. In populations where wild-type diphtheria has not circulated for years, adults lack natural immune boosting. This was the case for adults in post-Soviet countries during the 1990s, where an entire generation not covered by previous mass vaccination campaigns became a susceptible reservoir [28]. Thus, unprotected adults, whether they have never been vaccinated or are overdue for a booster, constitute a key risk group, particularly when exposed to imported infections.

Travelers to endemic regions are also at risk. They may be exposed to infection if not adequately vaccinated. This applies to tourists, humanitarian workers, and military personnel alike [30]. Risk is also elevated in populations living in poor sanitary conditions. Diphtheria spreads more easily in settings with close human contact and limited hygiene, such as overcrowded environments that facilitate droplet transmission or contact with contaminated surfaces [30]. Outbreaks among refugees, prisoners, or slum dwellers are especially concerning [34].

Healthcare personnel and caregivers are also at risk during outbreaks. When diphtheria clusters occur, individuals caring for patients, such as doctors, nurses, and paramedics, may be exposed to the disease. Standard protocol includes verifying their vaccination status and administering prophylactic antitoxin or antibiotics if exposure is suspected. While medical staff in developed countries are usually vaccinated, such protection may be lacking in resource-poor settings. Nevertheless, the main drivers of transmission are patients and those they interact with, not well-protected healthcare professionals [35,36].

Epidemiological challenges and controversies

Despite the availability of effective vaccines, new challenges have emerged in recent years that hinder full control of diphtheria. One such challenge is the rise of vaccine hesitancy. In many countries, a decline in public trust in vaccination has been observed, driven by misinformation and fear of adverse reactions. In high-income countries, anti-vaccine movements have contributed to reduced childhood immunization rates, creating clusters of susceptible individuals vulnerable to the re-emergence of diseases previously under control. In developing countries, logistical, cultural, and religious barriers also play a significant role in limiting vaccine coverage. This phenomenon affects diphtheria vaccination as

well. According to the WHO, vaccine hesitancy has become one of the global threats capable of reversing prior successes in diphtheria elimination [38]. For example, in Ukraine, between 2010 and 2016, DTP3 vaccination rates dropped to alarmingly low levels due to the spread of anti-vaccine sentiment, contributing to a resurgence of polio and raising concerns about a potential diphtheria epidemic. Similar trends, although on a smaller scale, have been observed in Western Europe and the United States, where local declines in child vaccination rates increase the risk of diphtheria transmission in the event of bacterial importation. Combating misinformation and educating the public about vaccine safety and efficacy remains a critical priority to sustain herd immunity [37].

In many parts of the world, basic immunization programs still do not reach all children. Geographic isolation (e.g., remote villages) and economic and social disparities prevent parts of the population from receiving required vaccinations. According to WHO data, global DTP3 coverage has stagnated at approximately 86% over the past decade, with no notable improvement [27]. Moreover, there was a marked setback between 2020 and 2021: global DTP3 coverage dropped from 86% in 2019 to just 81% in 2021 – the most significant decline in decades. In 2021, approximately 20 million children worldwide did not receive the full course of diphtheria vaccination, including 14.5 million who had not even started the schedule [33]. This issue primarily affects low-income countries, where healthcare systems face shortages of funding, personnel, and infrastructure. Access to vaccines can also be disrupted during crises, as in Venezuela, where currency shortages led to interruptions in vaccine supply. Likewise, in conflict zones, the distribution and transportation of vaccines may be severely constrained [27].

Interruptions or neglect in vaccination schedules also disrupt diphtheria control efforts. Program continuity can be compromised not only by vaccine refusal, but also by unforeseen events such as the COVID-19 pandemic. The consequences of the pandemic in 2020–2021 were devastating for routine childhood immunizations worldwide, as the suspension of clinical services and diversion of resources toward pandemic response caused delays and cancellations of many vaccination campaigns [27]. This led to the most significant drop in global immunization coverage since the 1990s, with DTP3 rates falling to their lowest levels in approximately 20 years [39]. Although a partial recovery was observed in 2022–2023 (reaching around 84% in 2023), pre-pandemic levels have not yet been fully restored [33]. This loss of continuity has resulted in a larger population of children susceptible to diphtheria and other preventable diseases.



The situation in Poland

Although Poland remained free of diphtheria cases for many years, recent developments have raised concerns about the potential re-emergence of the disease [40]. In 2021, the first confirmed case of diphtheria in over two decades was reported, alarming the medical and epidemiological communities. The patient was a 41-year-old Ukrainian man living in poor social conditions in Poland. He was diagnosed with the cutaneous form of diphtheria caused by a toxigenic strain of *C. diphtheriae*. The patient was homeless, suffered from chronic alcoholism and epilepsy, and lacked vaccination, all of which created favorable conditions for infection. This incident marked the actual return of diphtheria to Poland after more than 20 years without any reported cases [40]. In 2023, a fatal case of respiratory diphtheria was described in a Polish woman who had traveled to Germany and died from an infection caused by a toxigenic *C. diphtheriae* mitis biotype strain. Genetic analysis (next-generation sequencing – NGS) identified the strain as ST574, resistant to cotrimoxazole, and likely part of an undetected diphtheria cluster in Poland. Researchers suggested a possible link between this fatal case and the earlier cutaneous diphtheria case in a homeless man from the same region [41]. These incidents demonstrate that despite Poland's historical success in immunization programs, diphtheria remains a potential epidemiological threat, especially in the context of migration and the emergence of unvaccinated populations [41]. This phenomenon is not unique to Poland: similar challenges are being observed in other Central and Eastern European countries. According to the European Centre for Disease Prevention and Control (ECDC), between 2022 and 2023, a total of 281 confirmed diphtheria cases were reported in the European Union / European Economic Area (EU/EEA), most of them in Germany (206), followed by Belgium (37), Czechia (10), Slovakia (9), and the Netherlands (9). Most infections occurred in men aged 15–44 and residing in migrant reception centers, often in unsanitary conditions. Most cases reported in Czechia and Slovakia were cutaneous diphtheria and were associated with migrant populations; Slovakia recorded one fatal case in 2022. While countries such as Hungary and Romania did not report major outbreaks during this period, their geographical location and role in migration routes mean that future cases cannot be ruled out [32,46]. A shared priority across the region is to maintain high vaccination coverage, effective epidemiological surveillance, and international cooperation in identifying and controlling potential outbreaks [37].

PREVENTION AND THE IMPORTANCE OF VACCINATION

Vaccination is the cornerstone of diphtheria prevention. Vaccines contain diphtheria toxoid – an inactivated form of the toxin that stimulates antibody production [1]. These are usually administered in combination with tetanus toxoid and pertussis antigens: DTaP (for children), Tdap (for adolescents and adults), and DT or Td (for individuals with contraindications to pertussis vaccines) [1]. According to Centers for Disease Control and Prevention (Advisory Committee on Immunization Practices) guidelines, individuals over the age of 11 should receive a Tdap dose followed by Td booster doses every 10 years [14]. Vaccine-induced immunity may wane after 10–15 years, meaning that many adults have suboptimal antibody levels and require boosters [43]. Infection prevention also includes isolating infected individuals and providing prophylactic treatment to those with whom they have contact. Epidemiological surveillance plays a key role in the early detection and containment of outbreaks. Thanks to vaccination, diphtheria has been nearly eliminated in many countries [18].

MODERN DIAGNOSTICS AND PREVENTION OF DIPHTHERIA

Modern diagnostic approaches to diphtheria use advanced technologies. Matrix-assisted laser desorption/ionization-time of flight (MALDI-TOF) mass spectrometry allows for the rapid identification of *C. diphtheriae* strains based on protein profiles, though it does not assess toxigenicity [7]. Toxin production is confirmed using the lateral flow immunoassay (LFIA) strip test – a rapid immunoassay with high sensitivity and specificity [16]. Innovative molecular methods such as loop-mediated isothermal amplification (LAMP) can detect the *tox* gene without a thermocycler, making them suitable for field settings [17]. Research is also ongoing on biosensors that combine toxin detection with a signal output [17]. Classic diagnostics are supported by identification systems such as API Coryne, RapID CB Plus, and BBL Crystal, which provide rapid biochemical assessments [7].

Innovation in vaccines has brought about BR-TD-1001, a modern Td vaccine with high efficacy and safety for adolescents and adults [18]. DTP programs, introduced globally through the WHO's Expanded Programme on Immunization (EPI)



in the 1970s, have played a vital role in reducing diphtheria mortality [19,20,21]. Over time, combination vaccines (e.g., pentavalent formulations), booster doses, and maternal vaccinations were implemented [22]. The “cocooning” strategy, which involves vaccinating the close contacts of infants, helps reduce transmission [23]. Epidemiological investigations remain essential for controlling outbreaks, particularly in low-coverage countries [24]. In response to global shortages of equine DAT (eDAT), next-generation therapies are in development, including the human monoclonal antibody S315, which offers high efficacy and long-lasting protection [25], and recombinant scFv antibody fragments, which eliminate the risk of allergic reactions associated with animal-derived sera [26].

Future prospects

Despite the success of immunization programs, diphtheria continues to pose a potential epidemiological threat. Several key areas require strengthening in the future. Firstly, epidemiological surveillance must be further developed. The European Diphtheria Surveillance Network (EDSN) supports EU countries in monitoring and diagnostics, but additional investment in infrastructure and training is needed, especially in resource-limited settings [47]. Secondly, there is a need for alternative treatment options. Given the limited global availability of diphtheria antitoxin, research into monoclonal antibody therapies may offer more effective solutions in the future [48]. New vaccine technologies, especially thermostable formulations, could significantly improve vaccine supply to hard-to-reach areas and thus raise immunization coverage [49]. Parallel efforts should advance research on

C. diphtheriae carriage and herd immunity, to better understand transmission dynamics even in vaccinated populations [50]. Lastly, public education is crucial. Increasing skepticism toward vaccination necessitates effective communication strategies to raise awareness and rebuild trust in immunization [51].

CONCLUSIONS

Diphtheria is an infectious disease caused by *C. diphtheriae*, with its primary pathogenic factor being diphtheria toxin. Although the global incidence of diphtheria has significantly decreased due to widespread vaccination, recent years have seen a resurgence of cases in areas with low vaccination coverage and in regions affected by humanitarian crises. This underscores the need for continuous epidemiological surveillance and maintenance of high herd immunity. This review provided the historical and microbiological context for diphtheria, focusing on risk factors, transmission routes, and both global and local epidemiological trends. It also discussed the role of vaccination in reducing disease burden, the importance of preventive measures, rapidly identifying outbreaks, and actions to prevent transmission. While diphtheria is now rare in developed countries, it remains a global threat and has re-emerged in the form of local outbreaks, particularly in populations with reduced immunity. Therefore, ongoing monitoring, rapid epidemiological response, and updated vaccination strategies – including for adult populations – are essential.

All authors declare that they have contributed significantly to the work and that no ghostwriting or guest authorship took place.

Authors' contribution

Study design – M. Sulasz, J. Fiegler-Rudol

Data collection and interpretation – M. Sulasz, J. Fiegler-Rudol, K. Lau, J. Kasperczyk

Manuscript preparation – M. Sulasz, J. Fiegler-Rudol

Literature research – M. Sulasz, J. Fiegler-Rudol

Final approval of the version to be published – K. Lau, J. Kasperczyk



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Prebiotics: The foundation of preventive health care

Prebiotyki – fundament profilaktyki zdrowotnej

Wiktoria Ficoń¹ , Maksymilian Dobosz¹ , Beata Całyniuk²

¹Students' Scientific Club, Department of Human Nutrition, Faculty of Public Health in Bytom,
Medical University of Silesia, Katowice, Poland

²Department of Human Nutrition, Faculty of Public Health in Bytom, Medical University of Silesia, Katowice, Poland

ABSTRACT

INTRODUCTION: Prebiotics are substances that support the development and activity of the gut microbiota by stimulating the growth and function of the bacteria inhabiting the large intestine. These compounds are not digested in the human gastrointestinal tract. They include, among others, starches and dietary fiber.

MATERIAL AND METHODS: The research material consisted of a group of 140 individuals: 99 women and 41 men aged between 30 and 50 years. The research method used in the study was a diagnostic survey, with a proprietary questionnaire being the research tool.

RESULTS: The correct definition of the term “prebiotic” was selected by 57.1% of the respondents, while 25% confused it with probiotics. The terms “probiotic” and “prebiotic” were considered synonymous by 20% of respondents, whereas 12.1% were unable to answer the question. More than half of the respondents (57.6%) knew that probiotics can be combined with prebiotics, but only 48.6% could identify a range of products that contain them. According to 65% of respondents, prebiotics undergo fermentation in the digestive tract, which is the correct answer, whereas 35% provided an incorrect response.

CONCLUSIONS: Some respondents were aware of the positive effects of prebiotics on gut health. However, specific health benefits and prebiotic-rich products remain unclear to many. The results indicate a need for further public education, including a detailed explanation of the differences between prebiotics and probiotics and their role in human nutrition.

KEYWORDS

prebiotics, digestive system, bacteria, dietary fiber, gut microbiota

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Address for correspondence: Wiktoria Ficoń, Studenckie Koło Naukowe, Zakład Żywnienia Człowieka, Wydział Zdrowia Publicznego w Bytomiu ŚUM, ul. Jordana 19, 41-808 Zabrze, tel. +48 32 275 51 95, e-mail: s84514@365.sum.edu.pl



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STRESZCZENIE

WPROWADZENIE: Prebiotyki to substancje, które wspierają rozwój i aktywność mikrobioty jelitowej poprzez stymulację wzrostu i funkcjonowania bakterii zasiedlających jelito grube. Składniki te nie ulegają trawieniu w przewodzie pokarmowym człowieka. Należą do nich m.in. skrobia i błonnik pokarmowy.

MATERIAŁ I METODY: Materiał badawczy stanowiła grupa 140 osób – 99 kobiet i 41 mężczyzn w wieku od 30 do 50 lat. Metodą badawczą zastosowaną w analizie była ankieta diagnostyczna, a techniką badawczą autorski kwestionariusz.

WYNIKI: Poprawną definicję terminu „prebiotyk” wybrało 57,1% uczestników, podczas gdy 25% pomyliło go z probiotykiem. Określenia „probiotyk” i „prebiotyk” uznano za synonimiczne 20% respondentów, natomiast 12,1% nie potrafiło udzielić odpowiedzi na to pytanie. Ponad połowa uczestników badania (57,6%) wie, że prebiotyki można łączyć z probiotykami, ale jedynie 48,6% potrafi wskazać produkty, które je zawierają. Według 65% badanych prebiotyki ulegają fermentacji w przewodzie pokarmowym, co stanowi poprawną odpowiedź, podczas gdy 35% udzieliło błędnej odpowiedzi.

WNIOSKI: Niektórzy respondenci są świadomi pozytywnego wpływu prebiotyków na zdrowie jelit. Jednak dla wielu z nich konkretne korzyści zdrowotne oraz produkty bogate w prebiotyki pozostają niejasne. Wyniki wskazują na potrzebę dalszej edukacji społeczeństwa, w tym szczegółowego wyjaśnienia różnic między probiotykami a prebiotykami oraz ich roli w żywieniu człowieka.

SŁOWA KLUCZOWE

prebiotyki, układ trawienny, bakterie, błonnik pokarmowy, mikrobiota jelitowa

INTRODUCTION

The term “prebiotic” was introduced in 1995, defined as “an indigestible food ingredient that beneficially affects the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon” [1]. More than 20 years later, the International Scientific Association for Probiotics and Prebiotics (ISAPP) published a new definition that also includes low-carbohydrate substances with beneficial effects beyond the digestive tract. The positive health effects of individual substances must be supported by reliable research for them to be classified under this term [2]. Prebiotics can increase the population of probiotics, which most commonly are bacteria residing in the human gut; they have a positive impact on overall bodily function. Probiotic bacteria are part of the normal intestinal microbiota and they play a crucial role in inhibiting the growth of harmful bacteria as well as regulating the immune system. Probiotics cannot grow or conduct their own metabolic processes without a carbon source, which they obtain from carbohydrates [3].

Prebiotics primarily serve as a food source for beneficial bacteria present in the digestive tract. Their mechanisms of action can be classified into two types: direct mechanisms, which modulate the immune system by stimulating probiotic microorganisms, which in turn strengthens chemical, mechanical, biological, and immunological barriers, and indirect mechanisms, in which compounds such as short-chain fatty acids (SCFAs) and secondary metabolites of probiotics are produced and pathogens are eliminated. The metabolic by-products of probiotic bacteria can result in a lower pH in the colon, which is part of the large intestine. Proper acidity levels are essential for

maintaining the viability of probiotics, especially *Lactobacillus* and *Bifidobacteria*, allowing them to remain on the intestinal epithelium – where prebiotics exert their primary effects. SCFAs help maintain a balance in the gut microbiota, enhancing nutrient absorption, strengthening intestinal barrier function, and alleviating digestive disorders such as irritable bowel syndrome, Crohn’s disease, or ulcerative colitis [4,5,6,7].

Examples of prebiotics include plant fibers, which are edible parts of plants, or carbohydrate analogs resistant to digestion and absorption. These include inulin, gentiooligosaccharides, and fructooligosaccharides and are found in garlic, onions, nuts, and soy; resistant starches in legumes and cereals; lactulose, a synthetic form of lactose; stachyose, a complex sugar found in legumes such as beans and fava beans, as well as cruciferous vegetables like cabbage. These compounds undergo fermentation only in the large intestine because humans lack the necessary enzymes to hydrolyze complex polymer bonds – unlike gut microbiota – which leads to an increase in beneficial gut bacteria [8,9].

Prebiotic dietary fibers also influence mineral absorption, including calcium. The intake of lactulose, galactooligosaccharides, or inulin combined with oligofructose in doses ranging from 5 to 20 g/day significantly enhances calcium absorption [10]. During immunosenescence – the gradual aging of the immune system – the gut microbiota composition does not remain constant, but changes with age, leading to a decline in immunity. Maintaining a healthy microbiome can help delay aging-related processes, which contributes to longer global life expectancy [11,12]. Changes in the human microbiome occur in metabolic disorders such as obesity and diabetes, as well as neuropsychiatric conditions, including anxiety



and depression. A characteristic symptom is altered eating behaviors due to the strong connection between the gut–brain axis, which influences food preferences and intake quantity, thereby affecting calorie metabolism and various metabolic processes [13,14]. The gut–brain axis is a bidirectional communication system between the central nervous system and the gastrointestinal tract, in which the gut microbiota, the immune system, and neurotransmitters play key roles. In the absence of prebiotics – which are considered a food source for probiotics – the number of probiotics decreases, causing dysfunction in both the digestive and immune systems [15,16]. The use of an appropriate diet and dietary supplements containing probiotics and prebiotics improves mood and helps maintain or enhance cognitive functions during stressful situations, among other things [17,18]. Proper homeostasis is crucial for quality of life. A well-balanced gut microbiota is essential for protecting and supporting the intestinal mucosa, which undergoes continuous evolution due to changing environmental conditions. Ongoing research will lead to the discovery of additional benefits and new sources of prebiotics, as well as improved methods for supporting gut microbiota, ultimately contributing to disease prevention [19].

The aim of the study was to analyze the awareness and knowledge of survey participants regarding prebiotics, their role in maintaining health, and disease prevention.

MATERIAL AND METHODS

The study was conducted using a proprietary questionnaire consisting of 25 questions: 3 demographic questions and 22 substantive questions. The method used was computer-assisted web interviews (CAWI), which involves respondents completing the survey themselves via the internet. This method makes it possible to reach a wide range of participants quickly and conveniently, ensuring their anonymity and comfort when answering. The survey was carried out online via Google Forms from January 13 to February 19, 2025. Respondents were recruited through a direct link to the survey shared among the authors' acquaintances. Additionally, the link, along with a request to complete the survey, was posted on social media platforms such as Messenger and Instagram. Furthermore, via Facebook, the link was shared on numerous pages where users exchange information, advice, and news.

The survey included one open-ended question regarding age, while the remaining questions were closed-ended with single-choice answers, except for two questions allowing multiple-choice answers. The majority of the respondents (40 individuals) declared

their age to be within the range of 30–35 years (48.6%). The substantive questions focused on prebiotics – their definition, sources, impact on the human body, and interaction with probiotics. A total of 140 people participated in the study. The inclusion criterion for the study was an age in the range of 30–50 years.

The sampling was purposive and was conducted using a non-probabilistic method. Respondents were invited to participate in the study by sharing a link to the survey via social media and the authors' personal contacts. This recruitment strategy allowed for the rapid capture of data from participants fitting the profile of the study, but comes with limitations regarding the generalizability of the results to the population at large. The sample was not nationally representative, which needs to be taken into account when interpreting the survey results and formulating conclusions.

RESULTS

After the responses to the survey questions were analyzed and processed, the results were compiled in the form of pie charts generated using Google Forms. The study confirms the existence of a correlation between the results and the level of knowledge necessary to consciously care for one's health and to understand the significance of these important substances for the human body. This study verified the knowledge declared by respondents on the broad topic of prebiotics and identified areas where knowledge is insufficient.

The first standard question asked respondents to indicate the gender they identify with. The vast majority of the participants were women (70.7%, $n = 99$), while men accounted for 41 respondents, which corresponds to 29.3% ($n = 41$) of the total (Figure 1).

Sex

140 respondents

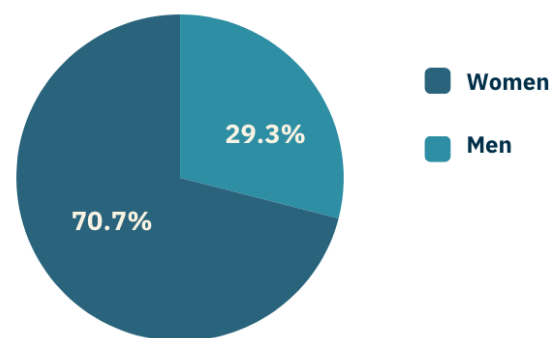


Fig. 1. Gender of the respondents



The only open-ended question in the survey concerned age. The largest numbers of respondents declared themselves to be 31 and 34 years old – each representing 10% ($n = 14$) of all participants. The oldest individuals taking part in the survey were 50

years old ($n = 7$), while the youngest group consisted of eight participants at the age of 30, making up 5.7% ($n = 8$) of the total. In terms of age distribution, the majority of the respondents (48.6%, $n = 68$) belonged to the 30–35 age group (Figure 2).

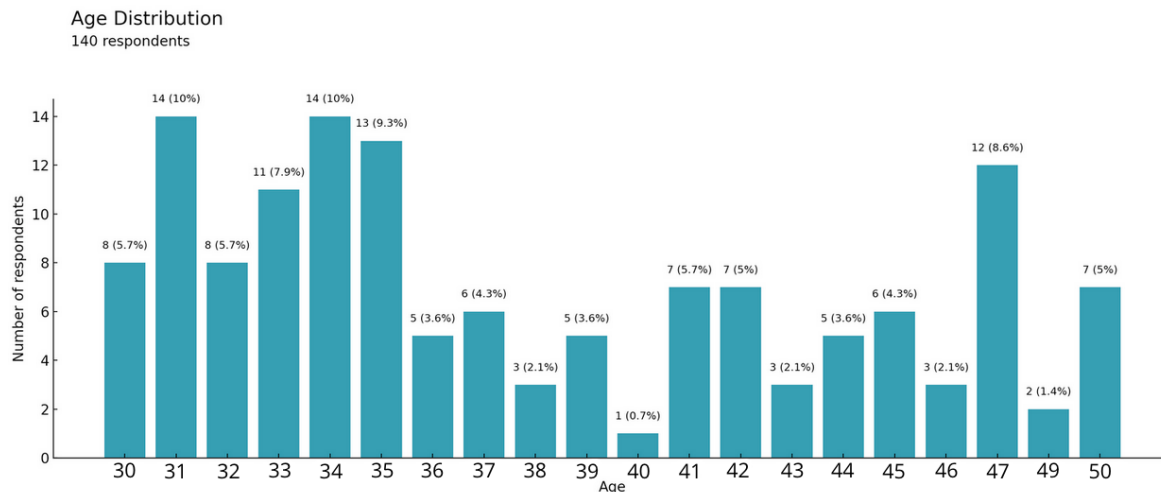


Fig. 2. Age of respondents

A correct definition of the term “prebiotic” was selected by 57.1% ($n = 80$), while 25% ($n = 35$) confused it with probiotics. Another 12.1% ($n = 17$) selected the definition of symbiotics, while the remaining group was unable to provide an answer to this question (Figure 3).

The terms “probiotic” and “prebiotic” were considered synonymous by 20% ($n = 28$) of the respondents, whereas 12.1% ($n = 17$) were unable to answer the question. These substances are not the same, though this was the response given by nearly three quarters of the respondents (Figure 4).

The next question was related to using probiotics concomitantly with prebiotics. The correct answer, yes, was marked by 57.9% ($n = 81$) of the respondents. A similar percentage (20.7%, $n = 29$ and 21.4%, $n = 30$) of them were unable to provide the correct answer (Figure 5).

In the question about which products contain prebiotics, nearly half of the respondents (48.6%, $n = 68$) provided the correct answer. A significant group (17.8%, $n = 25$) was unable to identify which products are rich in prebiotics. The smallest number of respondents (5%, $n = 7$) selected honey, which also contains probiotics (Figure 6).

Probiotics offer a range of health benefits for humans,

yet only 42.1% ($n = 59$) of the respondents are aware of all the listed advantages. Meanwhile, 12.1% – equivalent to 17 respondents – do not consume any probiotic-containing products and are therefore unable to identify their positive effects (Figure 7).

More than 40% ($n = 58$) of the respondents indicated that all the listed substances are prebiotics. Another 17.9% ($n = 25$) believed that only dietary fiber falls into this category and 10% ($n = 14$) that only linoleic acid isomers qualify, while 6.4% ($n = 9$) considered polyunsaturated fatty acids to be the correct answer. The remaining respondents (24.4%, $n = 34$) were unable to provide an answer to this question (Figure 8).

For the only true-or-false question – whether prebiotics undergo fermentation in the digestive tract – 91 respondents, accounting for 65%, selected the correct answer, while 35% ($n = 49$) provided an incorrect response (Figure 9).

When asked which prebiotics support the growth of specific probiotic bacteria, 37.8% ($n = 53$) of the respondents selected an incorrect answer, while 20% ($n = 28$) answered “I don’t know.” The correct answer – that prebiotics influence each listed group of probiotic bacteria – was selected by 59 participants, accounting for 42.2% of the total (Figure 10).



What is the definition of the term 'prebiotic'?

140 respondents

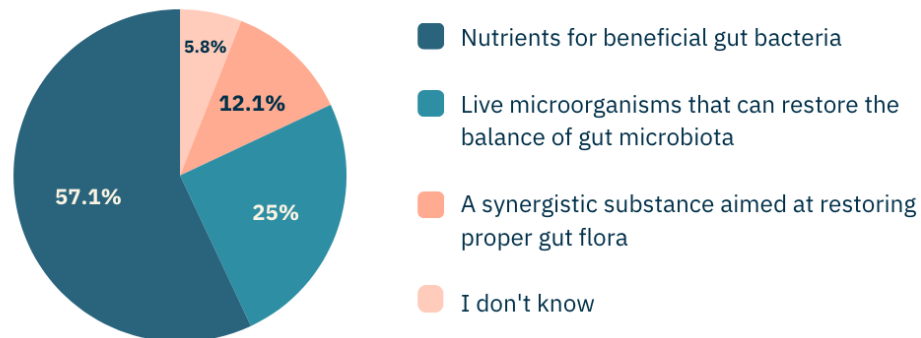


Fig. 3. Definition of the term "prebiotic" according to the respondents

Do you believe that the terms 'probiotic' and 'prebiotic' mean the same thing?

140 respondents

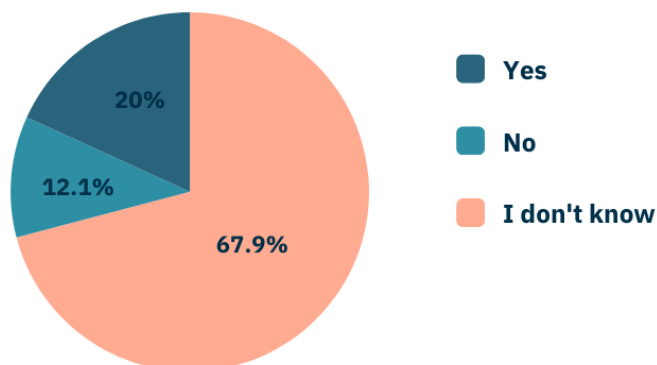


Fig. 4. Identify of concepts according to the respondents

Do you believe that probiotics and prebiotics can be combined?

140 respondents

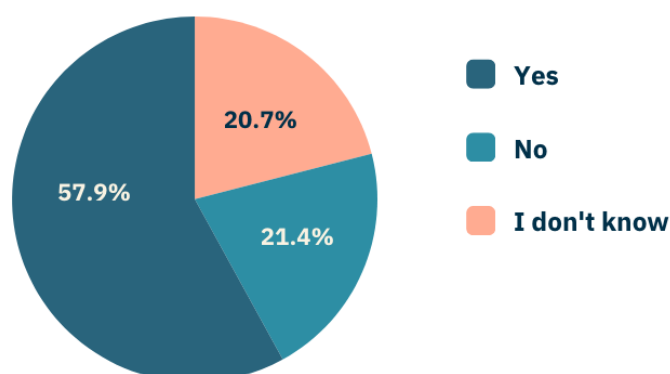


Fig. 5. Simultaneous use of prebiotics and probiotics according to the respondents



Please provide information on which products contain prebiotics:

140 respondents

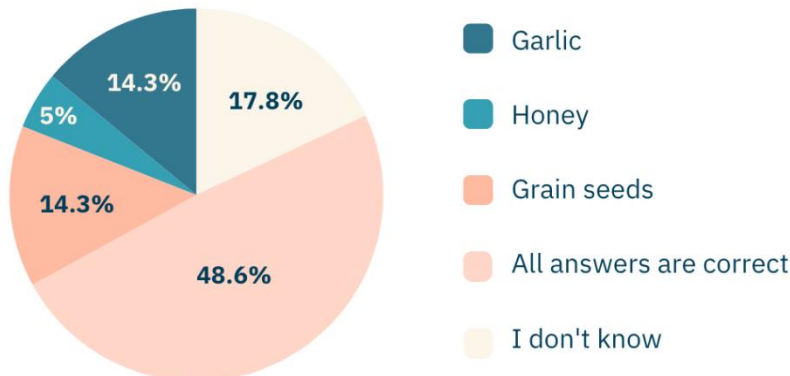


Fig. 6. Food sources of prebiotics according to the respondents

What health benefits result from consuming prebiotics?

140 respondents

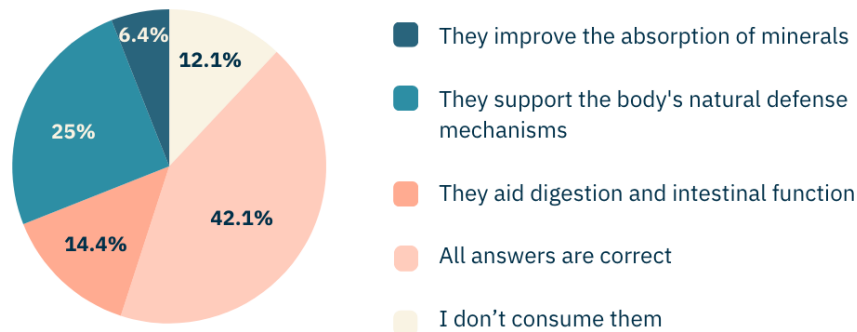


Fig. 7. Health benefits of prebiotics according to the respondents

Prebiotics include:

140 respondents

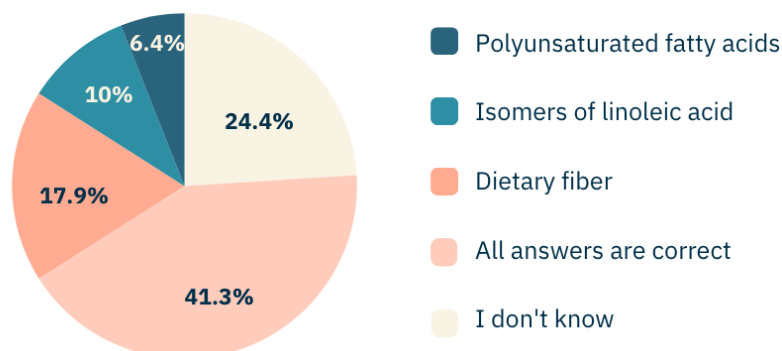


Fig. 8. Examples of prebiotics according to the respondents



Prebiotics undergo fermentation in the digestive tract.

140 respondents

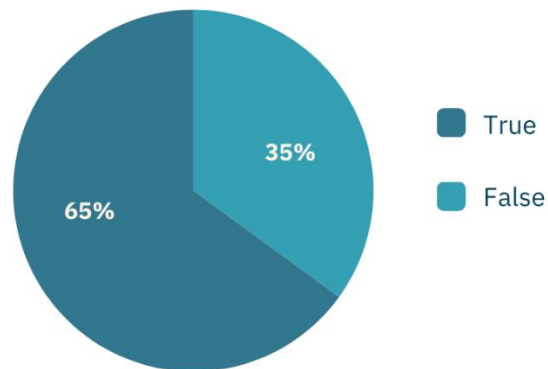


Fig. 9. Fermentation of prebiotics in the digestive tract according to the respondents

Prebiotics support the growth of bacteria from the genus:

140 respondents

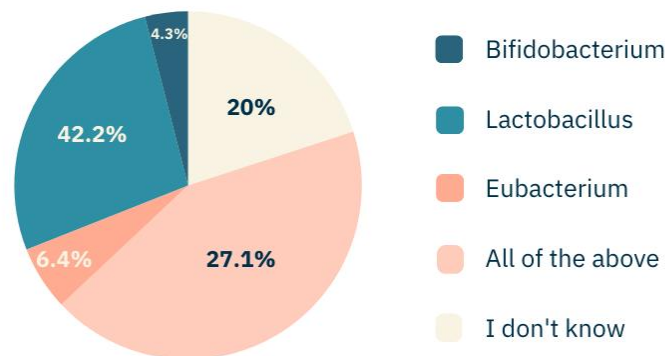


Fig. 10. Prebiotics and the growth of probiotic bacteria according to the respondents

DISCUSSION

Most respondents provided correct answers to the survey questions. However, an analysis of the overall study group reveals that their knowledge remains insufficient in certain areas. This indicates that some individuals within the 30–50 age range have gaps in their understanding that need to be addressed. It is assumed that some participants dedicated considerable time to exploring this topic due to the recent public discussion of gut microbiota. The findings of this study align with those of other researchers assessing knowledge on this subject.

The population of Saudi Arabia has been extensively studied across all age groups, making it relevant to cite a study that examined the knowledge of 50 doctors and dietitians there. In research conducted by King Abdulaziz University, 48.6% of the respondents were over 30 years old [1]. Among the surveyed doctors, 61.9% correctly identified the definition of “prebiotic,” as did 57.1% of hospital-

-employed dietitians, totaling 59.5% of all respondents. In this study, the reported percentage was very similar (57.1%). Another study on Saudi Arabian women found that nearly three quarters of the participants could correctly define prebiotics, with 51.4% recognizing their positive impact on the digestive system [20].

The Queensland Centre for Population Research carried out a social survey in Australia in 2017. Only one third (35.3%) of the participants were able to identify what prebiotics are, while more than half (58.6%) either did not know or had never heard of the term, suggesting that prebiotics are often overlooked in daily life [21]. Completely different results were obtained in Romania, where the participants were divided into two groups – adolescents and adults – over a three-month study period. Assessing respondents’ awareness of the concept of prebiotics, 74% stated they were familiar with it, whereas one quarter had never heard of it before. More than half of those surveyed did not know that the foods they consume could stimulate the growth of probiotic



bacteria, potentially improving their health. Additionally, nearly 30% of the respondents believed that the primary benefits of consuming prebiotic compounds were improved digestion, immune system support, enhanced nutrient absorption, and body detoxification. In a questionnaire designed by the authors, 42.1% of the respondents correctly answered a similar question, indicating that Polish society possesses slightly greater knowledge in this area. It is also worth mentioning opinions on who should be responsible for communicating such important information. The most common response pointed to healthcare professionals, due to their expertise and qualifications. The second most cited source was social media, which is understandable given its vast reach, though it carries the risk of spreading misinformation [22].

In the Indian state of Maharashtra, a study was conducted with 104 dental postgraduate students. When asked to distinguish between probiotics and prebiotics, 45.1% provided the correct answer. It was noted that the respondents had varying perspectives on simultaneous supplementation with these compounds which play a crucial role in gut health. Most believed that this approach constituted microbiome therapy aimed at restoring microbiota balance. Some preferred multibiome therapy, a newer and broader concept that considers not only gut microbiota, but also the skin, oral, and lung microbiomes. The smallest group of respondents considered both options [23].

It is well recognized how important health education is, especially among older adults. At a university hospital in Canada, 122 patients over the age of 50 completed a questionnaire assessing their knowledge of prebiotics, probiotics, and symbiotics. They were then taught about these topics, and the survey was repeated two weeks later. When asked whether prebiotics provide essential energy to probiotics for proper functioning, 64.75% were initially unable to answer, while 32.79% agreed with the statement. After explaining these concepts, a significant increase in correct responses was observed, with 79.51% affirming the statement and only 17.21% remaining uncertain. When asked whether foods such as bananas, onions, and oats contain prebiotics, the most common response was “I don’t know” (72.95%). Following the educational intervention, this percentage dropped to 18.85%. This study was the first to illustrate the importance of explaining key concepts to older adults, contributing to their expanded knowledge through well-structured education [24].

The studies cited from various parts of the world indicate that a portion of society lacks fundamental knowledge about prebiotics. The lack of awareness regarding their beneficial effects on the body may lead to health issues in the future. Few people can distinguish between the more commonly known probiotics and prebiotics, highlighting the need to continue educational efforts on this topic across different age groups.

CONCLUSIONS

This study provides valuable insights into the current level of awareness, knowledge, and beliefs regarding prebiotics among the Polish population aged 30–50 years. The results indicate a sufficient level of knowledge about prebiotics among the participants. However, despite this, it is essential to continue promoting awareness on this topic through various preventive and educational initiatives accessible to all Polish residents. The findings of this brief study may serve as a foundation for further research by other scientists in this field, as the subject is broad and increasingly significant due to the growing number of recent scientific reports.

Based on an analysis of the results and all relevant aspects of the topic, the following conclusions were drawn:

1. Most Poles in the 30–50 age group are knowledgeable about prebiotics; however, some still confuse them with probiotics and are unaware of their positive effects on the body.
2. Research has shown that, despite widely available information, knowledge remains insufficient. To effectively address this issue, various initiatives should be implemented for all age groups, with a special emphasis on individuals who do not use the internet.
3. It is necessary to both increase the number of information campaigns and expand their reach. Education should take place in schools by integrating topics related to probiotics, prebiotics, symbiotics, and postbiotics into the curriculum of elementary and secondary schools. Additionally, healthcare facilities such as clinics, hospitals, and pharmacies should provide access to information about the effects of these substances on the proper functioning of the digestive system, with particular attention to gut microbiota.

**Author's contribution**

Study design – W. Ficoń, M. Dobosz

Data collection – W. Ficoń, M. Dobosz

Data interpretation – W. Ficoń, M. Dobosz

Manuscript preparation – W. Ficoń, M. Dobosz, B. Całyniuk

Literature research – W. Ficoń, M. Dobosz

Final approval of the version to be published – W. Ficoń, M. Dobosz, B. Całyniuk

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Assessment of body-esteem and attitudes toward various weight loss support methods among young adult women and men

Badanie poziomu samooceny ciała oraz stosunku do różnych metod wspomaganie redukcji masy ciała u młodych kobiet i mężczyzn

Zofia Graca¹, Tomasz Wołoszczuk¹, Jakub Kołodziej¹, Aleksandra Skowronek¹, Karolina Lau² , Janusz Kasperczyk² 

¹Students' Scientific Club, Department of Environmental Medicine and Epidemiology, Faculty of Medical Sciences in Zabrze, Medical University of Silesia, Katowice, Poland

²Department of Environmental Medicine and Epidemiology, Faculty of Medical Sciences in Zabrze, Medical University of Silesia, Katowice, Poland

ABSTRACT

INTRODUCTION: Excess body weight, which affects nearly 60% of the adult Polish population, remains a growing public health and social concern by increasing the risk of chronic diseases and negatively impacting mental health. Women are more likely than men to experience societal pressure related to body image and weight. While weight reduction primarily comes from dietary changes and increased physical activity, modern medicine also offers various pharmacological and non-pharmacological approaches. This study aimed to assess body image and weight self-evaluation among young adults aged 18–35, identify their weight-related goals, and examine their attitudes toward selected weight loss support methods, with a consideration of the influencing factors.

MATERIAL AND METHODS: A total of 406 individuals completed an anonymous online questionnaire. The Polish adaptation of the BESAA scale was used to assess body-esteem across three subscales. A 5-point Likert scale measured the respondents' self-evaluation and attitudes toward dietary supplements, GLP-1 analogs, and bariatric surgery. Statistical analysis was conducted using Statistica 13.3.

RESULTS: The median BMI was 22.1 for women and 25.2 for men. Overall, 76.4% had attempted weight loss in the past. Women more often reported such attempts (81.2% vs. 63.7%) and expressed a desire to lose weight (61.7% vs. 46.9%). Participants with normal BMI reported significantly higher weight satisfaction. While bariatric surgery received the highest scores for effectiveness and safety among the listed methods, overall ratings for all approaches were quite low.

CONCLUSIONS: The findings underscore the need for education that promotes body acceptance, realistic body ideals, and informed use of weight loss methods.

KEYWORDS

weight loss, body self-esteem, obesity, bariatric surgery, dietary supplements, GLP-1 analogs, self-acceptance

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Address for correspondence: Zofia Graca, Studenckie Koło Naukowe, Katedra i Zakład Medycyny i Epidemiologii Środowiskowej, Wydział Nauk Medycznych w Zabrze SUM, ul. Jordana 19, 41-808 Zabrze, tel. +48 32 272 28 47, e-mail: s82800@365.sum.edu.pl



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STRESZCZENIE

WSTĘP: Nadmierna masa ciała, występująca u niemal 60% dorosłych Polaków, pozostaje rosnącym problemem zdrowotnym i społecznym, zwiększając ryzyko chorób przewlekłych oraz negatywnie wpływając na zdrowie psychiczne. Kobiety częściej niż mężczyźni odczuwają presję społeczną związaną z wyglądem i wagą. Mimo iż podstawowa strategia redukcji masy ciała obejmuje modyfikację diety i aktywność fizyczną, współczesna medycyna oferuje także różne metody farmakologiczne i zabiegowe. Celem badania była ocena obrazu ciała i samooceny masy ciała u młodych dorosłych w wieku 18–35 lat, identyfikacja ich celów związanych z masą ciała oraz analiza postaw wobec wybranych metod wspomagających redukcję masy ciała.

MATERIAŁ I METODY: Anonimowy kwestionariusz online wypełniło łącznie 406 osób. Do pomiaru samooceny ciała w trzech podskalach zastosowano polską wersję skali BESAA. 5-stopniowa skala Likerta służyła do pomiaru samooceny oraz postaw respondentów wobec suplementów diety, analogów GLP-1 i chirurgii bariatrycznej. Analizę statystyczną przeprowadzono z wykorzystaniem programu Statistica 13.3.

WYNIKI: Mediana BMI wyniosła 22,1 u kobiet i 25,2 u mężczyzn. Spośród respondentów 76,4% podejmowało w przeszłości próby redukcji masy ciała. Kobiety częściej zgłaszały takie próby (81,2% vs. 63,7%) oraz wyrażały chęć utraty wagi (61,7% vs. 46,9%). Uczestnicy z prawidłowym wskaźnikiem BMI wykazywali istotnie wyższy poziom zadowolenia z własnej wagi. Choć chirurgia bariatryczna uzyskała najwyższe oceny skuteczności i bezpieczeństwa spośród wymienionych metod, ogólne oceny wszystkich podejść były dość niskie.

WNIOSKI: Wyniki badania podkreślają potrzebę edukacji promującej akceptację własnego ciała, realistyczne wyobrażenia o swoim ciele oraz świadome stosowanie metod odchudzania.

SŁOWA KLUCZOWE

redukcja masy ciała, samoocena ciała, otyłość, chirurgia bariatryczna, suplementy diety, analogi GLP-1, samoakceptacja

INTRODUCTION

Excess body weight is an increasingly prevalent health and social issue. It is estimated that approximately 60% of adult Poles struggle with excess body weight, with nearly 40% classified as overweight and 21% as obese [1]. Obesity is a chronic, multifactorial disease that poses a significant challenge to modern medicine. It is defined as an excessive accumulation of adipose tissue that can adversely affect health and quality of life. According to the World Health Organization (WHO), overweight is diagnosed when the body mass index (BMI) is at least 25, while obesity is defined as a BMI equal to or exceeding 30 [2,3].

Obesity is a major risk factor for the development of numerous chronic diseases, including lipid metabolism disorders, hypertension, type 2 diabetes, atherosclerosis, osteoarthritis, and non-alcoholic fatty liver disease [4]. The impact of excess body weight on mental health and body image perception should not be underestimated. Individuals with obesity are often perceived as less valuable, unattractive, and neglectful, contributing to increased feelings of social exclusion [5]. Women are more likely than men to assess their appearance critically, struggle with body dissatisfaction, and experience low self-esteem, particularly those with body weights above or below the average [6,7]. There is also a notable correlation between body image satisfaction and overall self-esteem: greater dissatisfaction and frustration with appearance are associated with lower self-worth [7,8]. The primary strategy for weight reduction is lifestyle modification, including dietary changes to achieve a negative energy balance and increased physical

activity [9]. In advanced obesity or cases where diet and exercise prove ineffective, additional pharmacological or surgical interventions may be necessary. Numerous dietary supplements are available on the market, claiming to aid weight loss. However, a meta-analysis of the effectiveness of dietary supplements and alternative therapies in weight reduction indicates a lack of strong, high-quality evidence supporting the efficacy of such products and even suggests potentially dangerous side effects [10,11].

Pharmacotherapy for obesity is gaining interest, particularly with modern medications like semaglutide and tirzepatide. These drugs are agonists of the glucagon-like peptide 1 (GLP-1) receptor, influencing appetite regulation and glucose metabolism and thereby contributing to weight loss. Studies have demonstrated the effectiveness of these medications in treating excess body weight and type 2 diabetes, a common complication of obesity. They are recommended for individuals with obesity (BMI ≥ 30) or overweight (BMI ≥ 27) with at least one weight-related comorbidity. However, it is important to note that these are relatively new treatments, and their potential long-term adverse effects have not yet been fully identified and described [12,13].

Bariatric surgery represents a surgical approach to supporting weight reduction. It is currently the most effective method for treating obesity, especially severe obesity (BMI ≥ 40) with metabolic complications [14]. Bariatric procedures, indicated for individuals with a BMI of ≥ 40 or ≥ 35 and comorbidities when conservative treatment has failed, enable significant, sustained weight loss and improved metabolic parameters. Opinions on bariatric surgery are divided: some view it as effective and life-enhancing, while



others express concerns regarding its safety, associated risks, and social stigma [15,16]. Because effective weight reduction requires a negative caloric balance, implementing a personalized diet and physical activity plan is crucial for individuals with obesity, ideally following dietary consultation and, if indicated, supported by additional methods.

The aim of this study was to assess the body image and weight self-evaluation among young women and men (aged 18–35) and to identify their declared weight-related goals. The study also analyzed participants' attitudes toward selected weight loss support methods – dietary supplements, GLP-1 analogs, and bariatric surgery – in terms of their perceived effectiveness and safety. Additionally, the research aimed to determine the influence of BMI on the perception of these methods, examine differences in self-evaluation based on gender and BMI, and assess the relationship between weight-related goals and opinions on the effectiveness and safety of the selected strategies.

MATERIAL AND METHODS

The study was based on 406 completed questionnaires collected between March and April 2025. The use of computer-assisted web interviews (CAWI) enabled data collection through social media platforms. The inclusion criterion was an age between 18 and 35 years. Participation in the study was anonymous and voluntary. The sample was selected from incidental (self-selected) volunteers and therefore cannot be considered representative. The questionnaire consisted of three sections, the first of which included anthropometric and demographic data. The second section addressed the self-perception of body image across three domains and the assessment of current and past weight-related goals. To evaluate body image, the Polish adaptation of the Body-Esteem Scale for Adolescents and Adults (BESAA) was used, whose high reliability was confirmed by Słowińska [17] (Cronbach's $\alpha > 0.75$ for all subscales). The appearance subscale included 10 items, the weight subscale 8 items, and the attribution subscale 5 items. The third section focused on the participants' attitudes toward selected weight reduction methods, including dietary supplements, GLP-1 analogs, and bariatric surgery. The participants rated their overall attitudes as well as the perceived effectiveness and

safety of these methods. A 5-point Likert scale was applied to assess both body esteem and attitudes toward various weight management strategies. The data was subjected to statistical analysis, including the calculation of descriptive statistics. Inferential analysis was conducted using the Mann–Whitney U test, Kruskal–Wallis test, and chi-square (χ^2) test. A p-value of < 0.05 was considered statistically significant. All analysis was performed using Statistica 13.3. According to the opinion of the Bioethics Committee (No. BNW/NWN/0052/KB/85/25), the study did not require ethical approval.

RESULTS

A total of 409 responses were collected. Due to incomplete questionnaires, data from 406 participants (293 women and 113 men) were included in the final analysis. The vast majority of respondents ($n = 257$) were aged between 21 and 25 years. The study sample was predominantly composed of residents of large cities with populations exceeding 100,000. More than half of the participants ($n = 246$) were primarily engaged in intellectual work.

The median height among women was 167 cm, the median body weight was 63 kg, and the median BMI 22.1. In men, the corresponding values were 180 cm, 83 kg, and 25.2 (Table I). Based on BMI, the participants were categorized according to their body weight. Most respondents had a normal body weight (65.3%), followed by overweight individuals (22.9%). Based on self-reported height and weight, 7.1% were classified as obese and 4.7% as underweight. A statistically significant difference in BMI category between women and men was observed ($p < 0.001$). Normal body weight was recorded in 72% of women compared to 47.8% of men. Additionally, 17.1% of women were categorized as overweight, whereas this proportion reached 38.1% among men. Class III obesity was identified in three male participants and in none of the female respondents (Table II).

When asked for a subjective assessment of whether they eat healthily every day, over half of the participants (55.2%) answered “rather yes,” with no statistically significant difference between women and men ($p = 0.164$). Overall, 76.4% of the respondents had attempted to lose weight in the past, with women doing so significantly more often than men (81.2% vs. 63.7%, $p = 0.0002$; Table III, Figure 1).

**Table I.** Characteristics of the study group

Data	Total	Women	Men
Sample size [N (%)]	406 (100%)	293 (72.2%)	113 (27.83%)
Age [N (%)]			
18–20	40 (9.9%)	33 (11.3%)	7 (6.2%)
21–25	257 (63.3%)	195 (66.6%)	62 (54.9%)
26–30	59 (14.5%)	33 (11.3%)	26 (23.0%)
31–35	50 (12.3%)	32 (10.9%)	18 (15.9%)
Place of residence [N (%)]			
Rural area	85 (20.9%)	59 (20.1%)	26 (23.0%)
Town with < 20,000 inhabitants	31 (7.6%)	19 (6.5%)	12 (10.6%)
Town with 20,000–100,000 inhabitants	87 (21.4%)	60 (20.5%)	27 (23.9%)
City with > 100,000 inhabitants	203 (50.0%)	155 (52.9%)	48 (42.5%)
Type of work performed [N (%)]			
Mainly physical work	36 (8.9%)	22 (7.5%)	14 (12.4%)
Mainly mental work	246 (60.6%)	179 (61.1%)	32 (28.3%)
A combination of physical and mental work	124 (30.5%)	92 (31.4%)	67 (59.3%)
Anthropometric parameters			
Height [cm]	170.8	167.0	180.0
Body weight [kg]	67.0	63.0	83.0
BMI	23.0	22.1	25.2

BMI – body mass index.

Table II. Body mass index categories in the total sample and by gender [N (%)]

Category	Total	Women	Men
Underweight	19 (4.7%)	18 (6.1%)	1 (0.9%)
Normal weight	265 (65.3%)	211 (72.0%)	54 (48%)
Overweight	93 (22.9%)	50 (17.1%)	43 (38.0%)
Class I obesity	17 (3.2%)	9 (3.1%)	8 (7.1%)
Class II obesity	9 (2.2%)	5 (1.7%)	4 (3.5%)
Class III obesity	3 (0.7%)	0 (0.0%)	3 (2.7%)

Table III. Comparison of self-perceived eating habits and body weight goals, in the study group and by gender [N (%)]

Respondents' self-evaluation	Total	Women	Men	p-value
Do you consider your diet to be healthy?				
Definitely yes	40 (9.9%)	26 (8.9%)	14 (12.4%)	p = 0.164
Rather yes	224 (55.2%)	166 (56.7%)	58 (51.3%)	
Rather no	88 (21.7%)	67 (22.9%)	21 (18.6%)	
Definitely not	11 (2.7%)	5 (1.7%)	6 (5.3%)	
I have no opinion	43 (10.6%)	29 (9.9%)	14 (12.4%)	
Have you ever consciously tried to reduce your body weight in the past?				
Yes	310 (76.4%)	238 (81.2%)	72 (63.7%)	p = 0.0002
No	96 (23.6%)	55 (18.8%)	41 (36.3%)	
Currently, I would like to:				
Lose weight	233 (57.4%)	180 (61.4%)	53 (46.9%)	p = 0.016
Maintain my current weight	105 (25.9%)	73 (24.9%)	32 (28.3%)	
Gain weight	32 (7.9%)	17 (5.8%)	15 (13.3%)	
I haven't thought about it	36 (8.9%)	23 (7.8%)	13 (11.5%)	

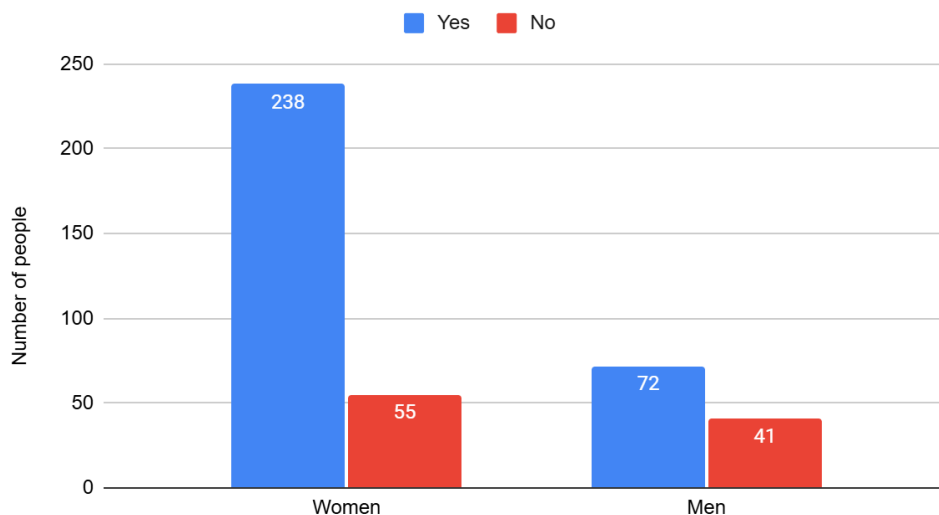


Fig. 1. Conscious attempts to reduce body weight in the past, by gender

The most frequently chosen weight reduction methods among the participants were as follows (in descending order): modification of dietary habits and/or increased physical activity, dietary supplements, consultation with a physician and/or dietitian, and GLP-1 analogs. One participant reported undergoing bariatric surgery as a method of weight reduction. Most respondents considered their past weight loss attempts effective, with no significant gender differences ($p = 0.243$; Table IV).

Regarding current weight-related goals, a general preference for weight loss was noted. This trend was observed both in the overall analysis and after stratifying the sample by gender. Statistical analysis revealed a significant association between gender and current body weight goals ($p = 0.016$). The women were more likely than the men to express a desire to lose weight, whereas the men more frequently reported either no concern about their weight or a desire to increase it (Table III, Figure 2).

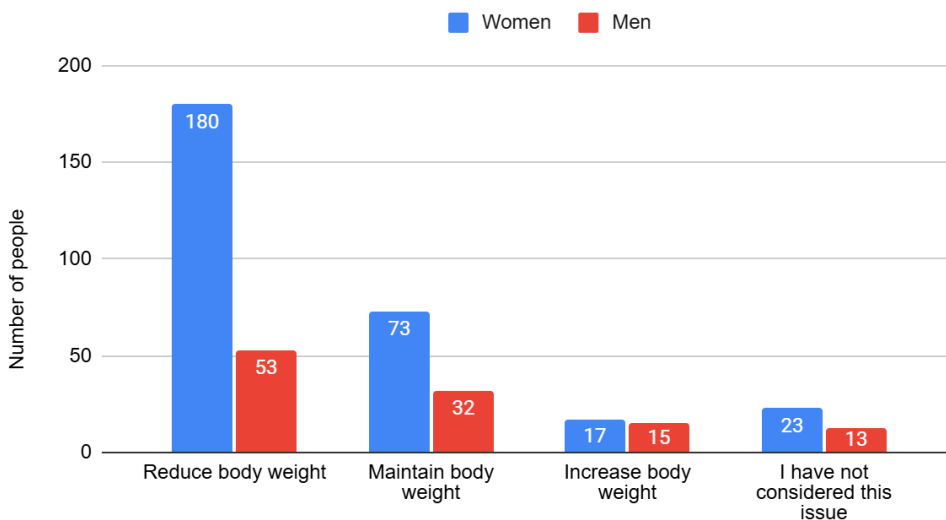


Fig. 2. Current body weight objectives by gender

When asked about the weight reduction methods they would be willing to use in the future, the participants most frequently indicated the following (in descending order): dietary habit modification and/or increased physical activity, consultation with a physician and/or dietitian, GLP-1 analogs, dietary supplements, and bariatric surgery.

In the part of the study aimed at assessing body self-esteem, the Polish adaptation of the BESAA scale was utilized. Median self-esteem scores were calculated across three dimensions: appearance self-esteem, weight self-esteem, and attributed evaluation. Each dimension included specific statements rated by the respondents using a 5-point Likert scale. The median



score for appearance self-esteem among women was 27.0, for weight self-esteem it was 20.0, and for attributed evaluation 16.0. Among the men, the respective medians were 26.0, 19.0, and 16.0. Statistical analysis did not reveal significant differences between women and men in terms of appearance self-esteem ($p = 0.080$) or attributed evaluation ($p = 0.720$). However, a statistically significant difference was found in weight self-esteem ($p = 0.002$), with the women rating their satisfaction with their body weight significantly higher on average (Table V).

The relationship between BMI and self-esteem was also analyzed. No significant differences in appearance self-esteem were observed between the subgroups classified by BMI category. However, statistically significant differences were found for both attributed evaluation ($p < 0.0001$) and weight self-esteem ($p < 0.0001$). Post hoc analysis for weight self-esteem revealed significant differences between participants with normal weight and those who were overweight ($p < 0.0001$), as well as between the normal weight group and the participants with obesity class I ($p = 0.021$). Individuals with normal body weight reported significantly higher levels of satisfaction with their weight than those with excessive body weight (Figure 3). The post hoc analysis regarding attributed evaluation showed significant differences between the following groups: underweight vs. obesity class II ($p = 0.016$), normal weight vs. overweight ($p = 0.002$), obesity class II vs. normal weight ($p < 0.0001$), and obesity class II vs. overweight ($p = 0.028$; Table VI).

The final section of the questionnaire examined the participants' assessment and comparison of attitudes toward three weight loss support methods, using

a 5-point Likert scale: dietary supplements, prescription medications (GLP-1 analogs), and bariatric surgery. No significant differences were observed between the sexes regarding general attitudes toward supplements ($p = 0.532$); however, the men rated their safety significantly higher than the women (3.00 vs. 2.00; $p = 0.021$). Bariatric surgery received the highest ratings, with a median safety score of 3.00 and an effectiveness score of 4.00. Overall attitudes toward this method were significantly more favorable among the women ($p = 0.009$; Table VII, Figure 4).

Further analysis examined the respondents' past weight loss experiences and their evaluations of each method (Table VIII). For dietary supplements, no statistically significant differences were found in general attitude ($p = 0.768$), perceived effectiveness ($p = 0.180$), or safety ($p = 0.326$), though individuals with no prior attempts to lose weight tended to rate the effectiveness and safety of supplements slightly higher than those who had previously attempted weight loss.

Additionally, the respondents' current weight-related goals were compared with their perceptions of each weight loss method (Table IX). In the case of supplements, significant differences in general attitude were observed between the subgroups ($p = 0.034$).

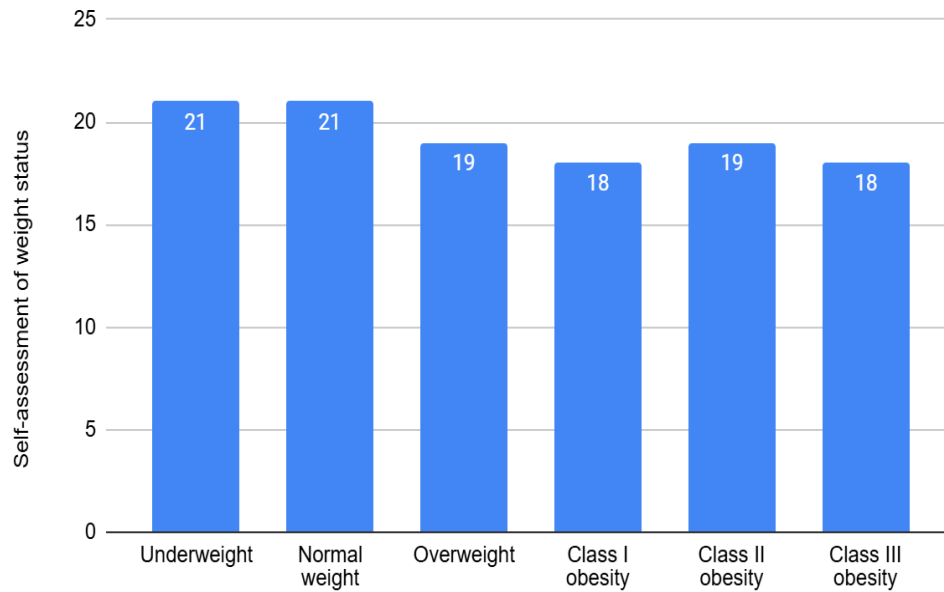
Table X, which included only participants currently intending to lose weight, revealed no statistically significant gender differences (all p -values > 0.200), suggesting more uniform perceptions of the weight loss methods between sexes. Similarly, no significant differences were observed across BMI categories; the median test results ($p > 0.05$) indicated a comparable distribution of responses regardless of weight classification.

Table V. Median scores of the Body-Esteem Scale for Adolescents and Adults (BESAA) subscales, in the study group and by gender

BESAA subscales	Total	Women	Men	p-value
Appearance self-esteem	26.0 $\pm$ 3.028	27.0 $\pm$ 2.983	26.0 $\pm$ 3.116	$p = 0.080$
Weight self-esteem	20.0 $\pm$ 3.295	20.0 $\pm$ 3.153	19.0 $\pm$ 3.509	$p = 0.002$
Attributed evaluation	16.0 $\pm$ 4.429	16.0 $\pm$ 4.513	16.0 $\pm$ 4.223	$p = 0.720$

Table VI. Median scores of the Body-Esteem Scale for Adolescents and Adults (BESAA) subscales, by BMI category

BESAA subscales	Underweight	Normal weight	Overweight	Obesity class I	Obesity class II	Obesity class III	p-value
Appearance self-esteem	28.0 $\pm$ 2.590	26.0 $\pm$ 2.982	26.0 $\pm$ 3.042	25.0 $\pm$ 4.079	25.0 $\pm$ 2.455	25.0 $\pm$ 1.528	$p = 0.0764$
Weight self-esteem	21.0 $\pm$ 3.931	21.0 $\pm$ 3.114	19.0 $\pm$ 3.411	18.0 $\pm$ 2.176	19.0 $\pm$ 2.062	18.0 $\pm$ 3.512	$p < 0.0001$
Attributed evaluation	16.0 $\pm$ 4.067	17.0 $\pm$ 4.237	15.0 $\pm$ 4.102	15.0 $\pm$ 3.860	5.0 $\pm$ 3.969	9.0 $\pm$ 5.859	$p < 0.0001$

**Fig. 3.** Self-assessment of weight status, by body mass index category**Table VII.** Median ratings of respondents' attitudes toward weight loss support methods

Weight loss support method	Total	Women	Men	p-value
Supplements				
Overall attitude	2.00 ± 1.108	2.00 ± 1.084	2.00 ± 1.170	p = 0.532
Effectiveness	2.00 ± 1.098	2.00 ± 1.093	2.00 ± 1.106	p = 0.075
Safety	2.00 ± 1.123	2.00 ± 1.085	3.00 ± 1.191	p = 0.021
Prescription medications				
Overall attitude	3.00 ± 1.167	3.00 ± 1.166	2.00 ± 1.173	p = 0.956
Effectiveness	3.00 ± 1.266	3.00 ± 1.281	3.00 ± 1.230	p = 0.843
Safety	2.00 ± 1.150	2.00 ± 1.169	3.00 ± 1.094	p = 0.187
Bariatric surgery				
Overall attitude	3.00 ± 1.163	3.00 ± 1.145	3.00 ± 1.175	p = 0.009
Effectiveness	4.00 ± 1.133	4.00 ± 1.138	3.00 ± 1.114	p = 0.169
Safety	3.00 ± 1.078	3.00 ± 1.089	3.00 ± 1.045	p = 0.251

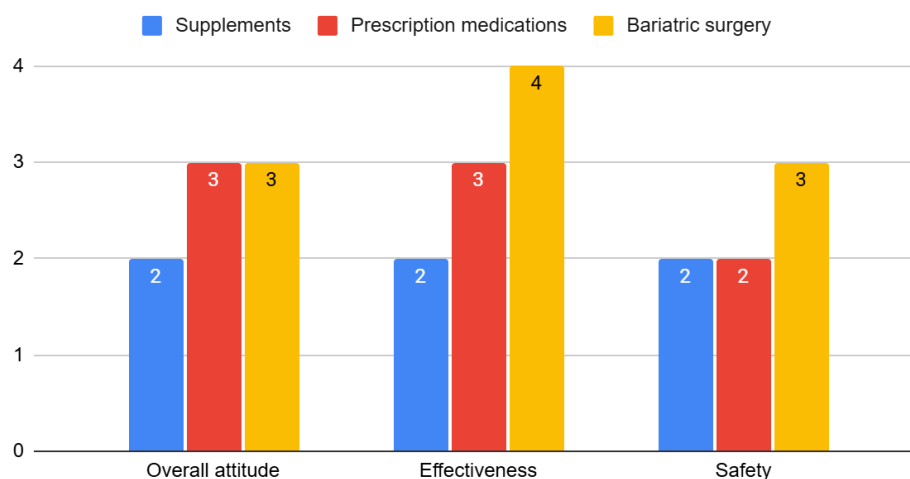
**Fig. 4.** Median ratings of respondents' attitudes toward weight loss support methods


Table VIII. Median ratings of attitudes toward weight loss methods, among individuals with and without previous weight loss attempts

Have you ever intentionally tried to lose weight in the past?			
Weight loss support method	Yes	No	p-value
Supplements			
Overall attitude	2.00 ± 1.111	2.00 ± 1.103	p = 0.768
Effectiveness	2.00 ± 1.084	2.00 ± 1.138	p = 0.180
Safety	2.00 ± 1.099	2.00 ± 1.195	p = 0.326
Prescription medications			
Overall attitude	3.00 ± 1.165	2.00 ± 1.179	p = 0.816
Effectiveness	3.00 ± 1.277	3.00 ± 1.223	p = 0.183
Safety	2.00 ± 1.163	2.00 ± 1.110	p = 0.785
Bariatric surgery			
Overall attitude	3.00 ± 1.172	3.00 ± 1.126	p = 0.273
Effectiveness	4.00 ± 1.157	3.00 ± 1.053	p = 0.355
Safety	3.00 ± 1.069	3.00 ± 1.111	p = 0.586

Table IX. Median ratings toward weight loss methods based on respondents' current body weight goals

Currently, I would like to:					
Weight loss support method	Lose weight	Gain weight	Maintain my current weight	I haven't thought about it	p-value
Supplements					
Overall attitude	2.00 ± 1.100	2.00 ± 1.435	2.00 ± 0.955	2.00 ± 1.171	p = 0.034
Effectiveness	2.00 ± 1.088	3.00 ± 1.164	2.00 ± 1.051	2.00 ± 1.219	p = 0.654
Safety	2.00 ± 1.106	3.00 ± 1.224	2.00 ± 1.154	3.00 ± 1.055	p = 0.539
Prescription medications					
Overall attitude	3.00 ± 1.195	2.00 ± 1.043	2.00 ± 1.179	2.00 ± 1.009	p = 0.088
Effectiveness	3.00 ± 1.286	3.00 ± 1.120	3.00 ± 1.238	3.00 ± 1.296	p = 0.045
Safety	3.00 ± 1.179	2.00 ± 0.976	2.00 ± 1.150	2.00 ± 1.059	p = 0.099
Bariatric surgery					
Overall attitude	3.00 ± 1.188	3.00 ± 1.085	3.00 ± 1.167	3.00 ± 1.100	p = 0.429
Effectiveness	4.00 ± 1.118	3.00 ± 1.228	3.00 ± 1.108	3.00 ± 1.108	p = 0.065
Safety	3.00 ± 1.102	2.50 ± 1.135	3.00 ± 1.033	3.00 ± 0.986	p = 0.960

Table X. Median ratings toward weight loss methods among individuals with a current goal to lose weight

Currently, I would like to lose weight.			
Weight loss support method	Women	Men	p-value
Supplements			
Overall attitude	2.00 ± 1.091	2.00 ± 1.137	p = 0.396
Effectiveness	2.00 ± 1.068	2.00 ± 1.159	p = 0.442
Safety	2.00 ± 1.071	2.00 ± 1.214	p = 0.321
Prescription medications			
Overall attitude	3.00 ± 1.194	3.00 ± 1.208	p = 0.748
Effectiveness	3.00 ± 1.307	3.00 ± 1.219	p = 0.639
Safety	2.00 ± 1.193	3.00 ± 1.126	p = 0.244
Bariatric surgery			
Overall attitude	3.00 ± 1.175	3.00 ± 1.223	p = 0.213
Effectiveness	4.00 ± 1.136	4.00 ± 1.062	p = 0.605
Safety	3.00 ± 1.116	3.00 ± 1.060	p = 0.835



DISCUSSION

Issues related to body image and weight acceptance among young women and men have been receiving increasing attention in the scientific community. In the context of the rising prevalence of lifestyle diseases such as obesity and depression, studies focusing on mental health and effective strategies for managing excess body weight are gaining importance. Modern culture – largely shaped by social media – promotes extreme beauty standards and body ideals, which may negatively affect self-perception, particularly among young women. At the same time, medicine faces the challenge of developing effective, long-term treatments for obesity, whose growing prevalence constitutes a major threat to public health. In addition to classic approaches based on dietary changes and physical activity, pharmacological and surgical interventions are also available, differing in indications, effectiveness, and public perception [3].

The results of the study provide valuable insight into gender differences in body perception, weight control behaviors, and attitudes toward weight loss methods. Although the average BMI for the overall group was within the normal range, gender-specific differences emerged: women had a normal BMI (median 22.1), while men showed a higher BMI (median 25.2). However, the BMI scale does not differentiate between fat and muscle mass, so excess muscle may account for elevated values in some individuals. Nevertheless, this finding aligns with statistics that indicate a higher prevalence of excessive body weight among men [1]. However, it remains unclear whether these favorable BMI values truly reflect the sample's characteristics or result from biased self-reporting. Even in anonymous surveys, participants may experience social pressure or shame, leading to underreporting of weight [18,19]. Despite having a normal BMI, women more often reported past weight-loss attempts and a current desire to lose weight than men. Conversely, men were less likely to express such intentions, despite having higher BMI. This may reflect persistent societal pressure for thinness among women and greater acceptance of excess weight in men [20,21].

Contrary to previous studies suggesting a higher appearance satisfaction among men, no significant gender differences were observed, possibly reflecting a convergence in body image standards across genders [22]. The BMI-based analysis showed that individuals with normal body weight reported significantly higher weight self-esteem and attributed evaluation scores compared to those with overweight or obesity, highlighting the role of physical parameters in body image. Women also assessed their body weight more positively than men. A meta-analysis suggests that

recent sociocultural shifts promoting body diversity and acceptance among women may be gradually mitigating the pressure to conform to ideals exalting thinness [23]. Additionally, men in this study had a higher median BMI and were more frequently classified as overweight, which may have contributed to lower weight satisfaction.

Despite these differences, overall body self-esteem in the sample was moderate to low. Median BESAA subscale scores were 26/50 (appearance), 20/40 (weight), and 16/25 (attributed evaluation), indicating low satisfaction with body image among young adults. The Polish version of the BESAA scale enabled a detailed assessment of self-esteem dimensions. A 2019 study on young Polish adults by Słowińska [17] using the BESAA revealed statistically significant gender differences. Women scored lower on the “Appearance” and “Weight” subscales than men, indicating greater dissatisfaction with body image and weight. In comparison to the present findings, these results suggest a potential narrowing of gender differences in body satisfaction over time. Moreover, the large sample size and demographic diversity support the reliability of the findings.

A limitation of the study is the reliance on self-reported height and weight, which may affect the accuracy of BMI values. Nevertheless, the results reveal important trends in body image and weight-related goals, emphasizing the need for educational efforts that promote body acceptance, gender equality, realistic health expectations, and the avoidance of unhealthy weight-loss practices.

The study demonstrates that among the three weight loss support methods it analyzed, bariatric surgery received the highest ratings – regardless of gender, prior weight loss attempts, or current weight-related goals. Its perceived effectiveness and safety scores were the highest across all groups. In contrast, dietary supplements and prescription medications were both rated significantly lower, particularly in terms of perceived safety. The favorable assessment of bariatric surgery may reflect a growing awareness of its effectiveness in treating obesity and, simultaneously, an oversimplified perception of the procedure. Despite being an invasive intervention, it was considered relatively safe; however, its frequent selection as the most effective method may indicate limited awareness of the strict dietary and behavioral requirements necessary before and after surgery.

Notably, the similar ratings for supplements and prescription medications may indicate the respondents' inability to differentiate between these categories, possibly perceiving both as general “supportive products” for weight loss, without a clear understanding of their legal status, mechanisms of action, or health risks. The evaluation of bariatric surgery as highly effective and acceptably safe is



supported by previous studies [14,15], whereas the limited trust in supplements aligns with literature highlighting their ambiguous efficacy and limited market regulation [10,11]. The confusion between supplements and medications may also stem from insufficient health education, as previously reported in the contexts of self-treatment and unsupervised pharmacotherapy.

A major strength of the study lies in its multidimensional analysis of attitudes by gender, weight history, and current goals. Limitations include the use of an unverified method, self-reported data, and self-selection bias. The similar ratings of supplements and medications may be explained by the fact that the participants' knowledge was not assessed. Overall, the respondents expressed limited confidence in the effectiveness and safety of the analyzed weight loss methods, while showing greater trust in traditional strategies based on dietary modification, physical activity, and professional consultation.

CONCLUSIONS

1. Despite having significantly lower BMI values, women more often than men reported previous

weight-loss attempts ($p < 0.001$), reflecting strong sociocultural pressure and highlighting the need to promote body acceptance and realistic appearance standards.

2. Participants with normal BMI demonstrated higher levels of weight-related self-esteem. Nevertheless, the overall BESAA scores across the domains of appearance, weight, and social attribution indicate low body satisfaction in this population, suggesting the need for targeted educational programs that foster healthy self-perception.
3. Among the evaluated weight-loss methods, bariatric surgery received the highest ratings for effectiveness and safety; however, overall trust in pharmacological and surgical interventions was limited. The respondents clearly favored traditional strategies such as dietary changes and increased physical activity.
4. Given the observed similarity in how supplements and medications were rated, educational initiatives should address the legal status, mechanisms, and safety profiles of these products. Healthcare professionals should be involved in delivering clear guidance on evidence-based weight-loss methods, including the appropriate use of bariatric surgery.

Authors' contribution

Study design – Z. Graca, T. Wołoszczuk, K. Lau

Data collection – Z. Graca, T. Wołoszczuk, A. Skowronek, J. Kołodziej

Statistical analysis – J. Kasperczyk, Z. Graca, T. Wołoszczuk, A. Skowronek, J. Kołodziej

Manuscript preparation – Z. Graca, T. Wołoszczuk, A. Skowronek, J. Kołodziej

Literature research – Z. Graca

Final approval of the version to be published – K. Lau, J. Kasperczyk

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Opportunity or threat? A comparative study on the perception of artificial intelligence in dentistry among practitioners and patients

Szanse czy zagrożenia? Badanie porównawcze postrzegania sztucznej inteligencji w stomatologii wśród lekarzy i pacjentów

Miłosz Krysiak , Katarzyna Drobny 

Students' Scientific Club, Department of Environmental Medicine and Epidemiology,
Faculty of Medical Sciences in Zabrze, Medical University of Silesia, Katowice, Poland

ABSTRACT

INTRODUCTION: Artificial intelligence (AI) is increasingly being applied in dentistry – from radiological diagnostics and orthodontics to prosthesis design and practice management. AI's precision, speed, and potential for automating routine tasks position it as a promising tool to support clinicians, although it simultaneously raises doubts regarding acceptance and trust among both dentists and patients.

MATERIAL AND METHODS: In May 2025, a cross-sectional online survey was conducted via Google Forms with 101 respondents: 25 dentists (24.75%) and 76 patients (75.25%). The questionnaire was comprised of both closed-ended and multiple-selection questions addressing AI awareness, trust levels in AI-supported diagnoses and treatment plans (rated on a 1–5 scale), therapeutic preferences, perceived benefits, and concerns regarding AI in dentistry.

RESULTS: The dental practitioners demonstrated higher trust in AI-supported diagnoses than patients, with mean trust scores of 2.92 versus 2.42, respectively. Trust levels increased significantly along with self-reported knowledge of AI, reaching mean values of 3.20 for “high” and 4.00 for “very high” familiarity. In a hypothetical scenario with equal error rates, 79.21% of respondents would favor a dentist supported by AI, 18.81% preferred human-only care, and only 1.98% would trust AI alone.

CONCLUSIONS: AI in dentistry offers tangible diagnostic and organizational advantages; however, the principal barriers to its implementation are insufficient trust and limited user knowledge. One of the greatest challenges in modern public health is educating both patients and professionals about the capabilities and limitations of AI, a prerequisite for increasing acceptance and fully harnessing AI's potential in clinical practice.

KEYWORDS

artificial intelligence, dentistry, trust, education, public health

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Address for correspondence: Miłosz Krysiak, Studenckie Koło Naukowe, Katedra i Zakład Medycyny i Epidemiologii Środowiskowej, Wydział Nauk Medycznych w Zabrzu SUM, ul. Jordana 19, 41-808 Zabrze, tel. +48 32 272 28 47, e-mail: s68711@365.sum.edu.pl



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STRESZCZENIE

WSTĘP: Sztuczna inteligencja (*artificial intelligence* – AI) jest coraz częściej stosowana w stomatologii – od diagnostyki radiologicznej i ortodoncji po projektowanie protetyczne i zarządzanie praktyką. Wysoka precyzja, szybkość i potencjał w zakresie automatyzacji rutynowych zadań sprawiają, że jest to obiecujące narzędzie wspierające klinicystów, choć jego powszechne wdrożenie napotyka na bariery związane z akceptacją i zaufaniem zarówno wśród dentystów, jak i pacjentów.

MATERIAŁ I METODY: W maju 2025 r. przeprowadzono przekrojowe badanie ankietowe online za pomocą Formularzy Google z udziałem 101 respondentów: 25 lekarzy dentystów (24,75%) i 76 pacjentów (75,25%). Kwestionariusz składał się z pytań zamkniętych i wielokrotnego wyboru, dotyczących wiedzy na temat AI, poziomu zaufania do diagnoz i planów leczenia wspomaganych przez AI (ocenianych w skali 1–5), preferencji terapeutycznych oraz postrzeganych korzyści i obaw, związanych ze stosowaniem AI w stomatologii.

WYNIKI: Lekarze dentyści mieli większe zaufanie do diagnoz wspieranych przez AI niż pacjenci, ze średnimi ocenami zaufania odpowiednio 2,92 i 2,42. Zaufanie znacząco rosło wraz z deklarowaną wiedzą na temat AI, osiągając średnie wartości 3,20 dla „wysokiej” i 4,00 dla „bardzo wysokiej” wiedzy. W przypadku gdy odsetek błędów byłby taki sam, 79,21% respondentów preferowałoby lekarza dentystę wspieranego przez AI, 18,81% opiekę świadczoną wyłącznie przez człowieka, a tylko 1,98% zaufałoby samej AI.

WNIOSKI: AI w stomatologii oferuje wymierne korzyści diagnostyczne i organizacyjne, jednak głównymi barierami w jej wdrażaniu są niedostateczne zaufanie i ograniczona wiedza użytkowników. Kluczowym wyzwaniem jest edukacja zarówno pacjentów, jak i specjalistów na temat możliwości i ograniczeń AI, co jest warunkiem wstępnym do zwiększenia akceptacji i pełnego wykorzystania potencjału AI w praktyce klinicznej.

SŁOWA KLUCZOWE

sztuczna inteligencja, stomatologia, zaufanie, edukacja, zdrowie publiczne

INTRODUCTION

Artificial intelligence (AI) is becoming an integral component of modern dental practice [1,2,3,4]. It is increasingly being applied in various areas of dentistry, including diagnostics, dental radiology, orthodontics, and treatment planning [5]. Specifically, AI algorithms now assist clinicians by automating the analysis of radiographic images to identify subtle signs of caries or periodontal disease [6,7], planning orthodontic treatments by predicting tooth movement [8], and optimizing the design of prostheses such as crowns and bridges within CAD/CAM systems to ensure a precise fit [9].

There is a growing body of evidence indicating that AI enhances the safety, efficiency, and precision of dental practice. For instance, deep learning models, a core branch of AI, have demonstrated high accuracy in radiographically detecting caries, sometimes exceeding that of human experts [6]. These systems can improve diagnostic consistency across different practitioners and support earlier intervention. However, the use of AI in healthcare also raises numerous questions and concerns, primarily centered around trust, accountability, and the future of the doctor–patient relationship [10]. This study compares the perception of AI in dentistry between two key stakeholder groups – dental practitioners and patients – to understand whether AI is viewed as a valuable assistant or a potential threat.

MATERIAL AND METHODS

Study design and participants

The study was designed as a cross-sectional survey conducted online in May 2025. The research tool was a questionnaire created using Google Forms. A total of 101 individuals participated in the study. The respondents were divided into two main groups: dental professionals ($n = 25$; 24.75%) and patients ($n = 76$; 75.25%). Convenience and snowball sampling methods were used to recruit participants.

Survey Instrument

The questionnaire consisted of closed-ended, single-selection, and multiple-selection questions, as well as questions utilizing a 5-point Likert scale. The original survey was conducted in Polish and was translated into English for the purpose of this manuscript. The survey was structured into five main domains:

1. Demographics and awareness of AI
2. Trust in diagnoses
3. Treatment preferences
4. Perceived benefits of AI
5. Concerns about AI in dentistry

Data collection and ethical considerations

The survey was distributed electronically and was fully anonymous and voluntary. Implied informed



consent was obtained from all participants. The study adhered to the principles of the Declaration of Helsinki.

Statistical analysis

The data collected in the survey was exported and analyzed. Descriptive statistics were used to summarize the characteristics of the study groups. To compare mean trust levels between the two groups, the independent samples t-test was used. To compare mean trust levels across more than two groups, one-way analysis of variance (ANOVA) was employed. Relationships between categorical variables were analyzed using the chi-squared (χ^2) test of

independence. A p-value of < 0.05 was considered statistically significant.

RESULTS

Participant characteristics

The study sample consisted of 101 respondents, of whom 75.25% ($n = 76$) were patients and 24.75% ($n = 25$) were dental practitioners. The detailed demographic and professional characteristics of the study participants are presented in Table I. The demographic profile of the participants, including age, gender, education, and place of residence, was collected for further analysis.

Table I. Demographic and professional characteristics of the study participants ($N = 101$)

Characteristic	Category	n (%)
Profession	Patient	76 (75.3%)
	Dentist	25 (24.8%)
Gender	Female	68 (67.3%)
	Male	33 (32.7%)
Age	21–30 years	52 (51.5%)
	31–40 years	22 (21.8%)
	41–50 years	14 (13.9%)
	51–60 years	8 (7.9%)
	Above 60 years	5 (5.0%)
Education	Secondary	15 (14.9%)
	Higher, current student	46 (45.5%)
	Higher	40 (39.6%)
Place of residence	Rural area	18 (17.8%)
	Town with $< 10,000$ inhabitants	11 (10.9%)
	Town with 10,000–50,000 inhabitants	15 (14.9%)
	City with 50,000–200,000 inhabitants	21 (20.8%)
	City with $> 200,000$ inhabitants	36 (35.6%)

Trust in AI-based diagnosis: A comparison between dentists and patients

A central objective was to assess the level of trust in a diagnosis formulated solely by an AI system. The analysis revealed a statistically significant difference between the two cohorts. The mean trust

score, on a 5-point Likert scale, was higher among the dentists ($M = 2.92$) than the patients ($M = 2.42$). An independent samples t-test confirmed this difference to be statistically significant ($p = 0.046$), suggesting that dental professionals are more inclined to trust AI-driven diagnostics than patients. This core finding is illustrated in Figure 1.

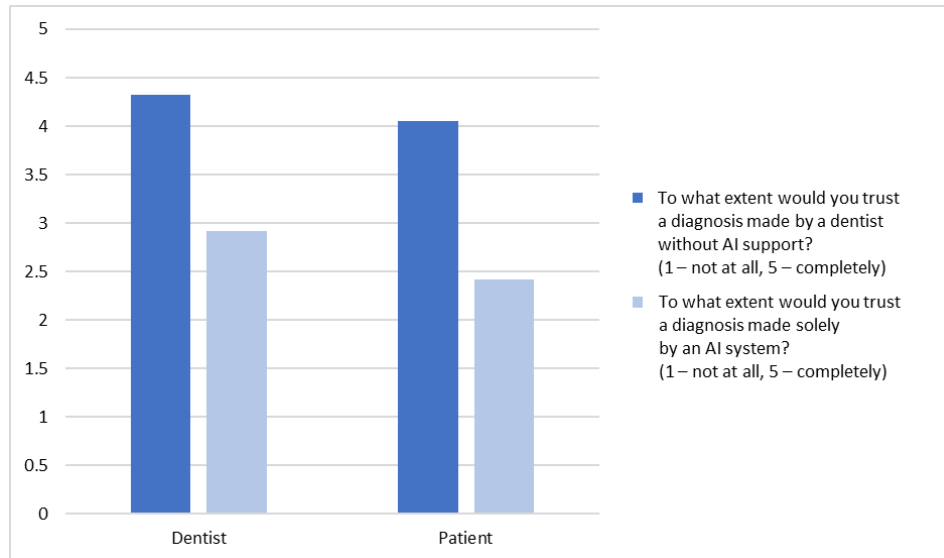


Fig. 1. Comparison of mean trust scores for an AI-only diagnosis, between dentists and patients

The impact of self-assessed AI knowledge on trust

The one-way ANOVA revealed a highly significant effect of self-assessed AI knowledge on the level of trust in AI diagnostics ($p < 0.001$). A clear trend was observed: trust levels were consistently low and stable among participants reporting “none” ($M = 2.41$),

“low” ($M = 2.40$), or “average” ($M = 2.47$) self-assessed knowledge. However, markedly higher trust was recorded for participants with “high” ($M = 3.20$) or “very high” ($M = 4.00$) knowledge. This demonstrates a strong positive correlation between familiarity with AI and willingness to trust it in a clinical setting (Figure 2).

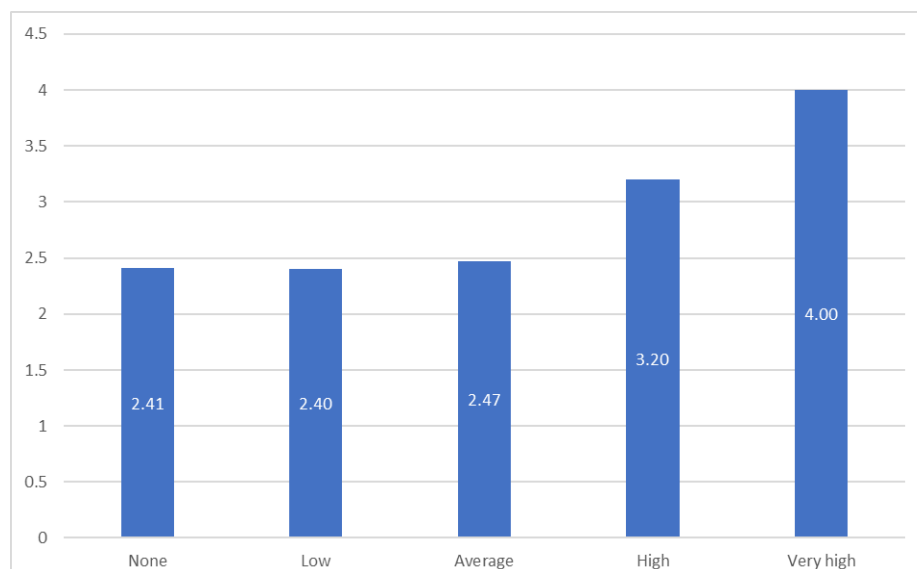


Fig. 2. Mean trust scores for an AI-only diagnosis based on self-assessed knowledge of AI

The influence of demographic factors on trust in AI

Further ANOVA testing was conducted to evaluate the influence of other demographic variables. A statistically significant relationship was identified

between the age of the respondents and their level of trust ($p = 0.027$), with younger cohorts generally demonstrating higher trust scores than older cohorts. In contrast, no statistically significant differences in trust levels were found based on the respondents' level of education ($p = 0.116$) or their place of residence



($p = 0.655$), suggesting that these factors were less influential in shaping perceptions within our study sample.

Preferences for AI-involved treatment models

The participants were presented with a hypothetical scenario to gauge their preference for different treatment models. The results show that the vast majority of respondents (79.21%) favored a “hybrid” model, where a dentist is supported by AI. A smaller group (18.81%) preferred a human-only approach, while a negligible fraction (1.98%) declared that they would trust an AI-only model. A chi-squared test for independence was performed to examine the relationship between the respondents’ role (dentist vs. patient) and their preferred treatment model. The analysis indicated no significant correlation between these variables ($p = 0.284$), suggesting a broad consensus across both groups on the desirability of a human-in-the-loop approach to the implementation of AI in dentistry.

DISCUSSION

The findings of this study provide a nuanced snapshot of the current perceptions of AI in Polish dentistry, highlighting a significant gap between its technological potential and its acceptance by key stakeholders. Our analysis confirms that the primary barriers to AI adoption are not technical, but deeply rooted in user trust, professional experience, and digital literacy [1].

Our first key finding is the statistically significant “trust gap” between dental professionals and patients. Our results are consistent with recent international studies, which found that while patients are generally optimistic about AI, they harbor significant concerns regarding the potential loss of the human element in care [10]. These perceptions within dentistry mirror the broader public sentiment towards AI, where a similar dichotomy of perceived opportunity and risk has been observed [5]. Indeed, the challenge of fostering patient trust while preserving the physician’s role is a central theme in the wider discourse on AI in medicine, extending to fields such as radiology and oncology [5].

Perhaps the most critical finding is the strong, positive correlation between AI knowledge and trust ($p < 0.001$). This underscores that trust is a dynamic variable that can be cultivated through education. This result strongly corroborates findings which demonstrate that less knowledge of AI is directly associated with higher perceived risk [10]. The need for this education is further emphasized by studies showing high patient interest in AI, provided that they feel informed and secure [10].

Furthermore, our analysis revealed a significant negative correlation between age and trust in AI ($p = 0.027$), with younger cohorts demonstrating higher levels of acceptance. This finding has crucial practical implications for the implementation of AI-driven tools in clinical settings. It suggests that a “one-size-fits-all” approach to patient education and communication may be ineffective. To ensure equitable adoption and to mitigate disparities, healthcare providers and policymakers should consider developing tailored strategies. For younger, digitally native patients, communication might focus on the technological capabilities and efficiency gains of AI. For older patients, the focus should instead be on building trust, emphasizing the role of AI as a supportive tool that remains under the full control of the human clinician, and using more traditional, interpersonal communication channels to address their specific concerns [1].

It is noteworthy that despite the varying levels of trust, a strong consensus emerged that a “human-in-the-loop” approach is preferred. This indicates a shared desire to leverage AI’s analytical power – proven to be effective in tasks such as detecting caries [6] – without sacrificing human oversight, a preference also noted in other studies on patient acceptance [10].

CONCLUSIONS

The successful integration of AI in dentistry hinges on a dual strategy: fostering trust through targeted educational initiatives for both the public and professionals and developing transparent, clinician-supervised AI systems that enhance, rather than replace, human expertise. Our research demonstrates that the primary challenge is not the capability of artificial intelligence itself, but rather the human response to it. Therefore, addressing the deficit in trust and knowledge is paramount to unlocking the full potential of AI to improve dental care outcomes.

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Conflict of interest

The authors declare no conflict of interest.



Appendix A: Survey Questionnaire

Title: The Impact of Artificial Intelligence on Dental Practice: The Perspective of Patients and Dentists

Introduction: The aim of this study is to analyze the attitudes, expectations, and concerns related to the use of artificial intelligence (AI) in dentistry. The survey is addressed to both dentists and patients. Participation in the study is anonymous, and its results will be used for scientific purposes only.

Part I: Respondent profile

Q1. Please specify which group you represent:*

- Patient
- Dentist

Q2. Gender:*

- Woman
- Man
- Other / Prefer not to say

Q3. Age:*

- 20 years or less
- 21–30 years
- 31–40 years
- 41–50 years
- 51–60 years
- Over 60 years

Q4. Place of residence (size of locality):*

- Rural area
- Town with < 10,000 inhabitants
- Town with 10,000–50,000 inhabitants
- City with 50,000–200,000 inhabitants
- City with > 200,000 inhabitants

Q5. Level of education:*

- Primary
- Secondary
- Higher, current student
- Higher

Part II: Awareness of and experience with AI

Q6. Have you encountered the use of artificial intelligence in your work?

- Yes
- No

Q7. Have you heard about the use of artificial intelligence in dentistry?*

- Yes
- No

Q8. Did you know that AI can analyze X-ray images or plan treatment?*

- Yes
- No

Q9. Have you ever been treated using AI-based technology?*

- Yes
- No

Q10. How do you rate your knowledge of AI in dentistry?*

- Very good
- Good
- Average
- Poor
- None



Part III: Perceptions, trust, and concerns

Q11. To what extent would you trust a treatment plan developed by AI under the supervision of a dentist?*

- Fully
- Partially
- I would not trust it

Q12. To what extent would you trust a diagnosis made solely by an AI system? (1 – would not trust at all, 5 – would trust very much)?*

- 1
- 2
- 3
- 4
- 5

Q13. To what extent would you trust a diagnosis made by a dentist without AI support? (1 – would not trust at all, 5 – would trust very much)?*

- 1
- 2
- 3
- 4
- 5

Q14. What would be the biggest benefit for you from the use of AI in a dentist's office?* (Multiple selections are possible.)

- Lower treatment costs
- Shorter visit time
- More accurate diagnosis
- Better communication
- None of the above
- Other: _____

Q15. In which areas can AI best support a dentist's work?* (Multiple selections are possible.)

- Analysis of X-ray images
- Treatment planning
- Medical documentation
- Time and appointment management
- Patient education
- Other: _____

Q16. What is your biggest concern related to AI in a dental office?* (Multiple selections are possible.)

- Algorithm errors
- Lack of human contact
- Not knowing who makes the decisions
- Job loss for dentists
- Lack of transparency / Knowledge of how it works
- Nothing concerns me, AI should be everywhere
- Other: _____

Q17. Do you believe that the use of AI can increase/decrease treatment costs?

- Increase
- Decrease
- No impact
- I don't know

Q18. Do you fear that AI might one day replace dentists?*

- Yes
- No



Part IV: Hypothetical scenarios

Q19. Imagine that you have to choose one treatment option. Which do you choose?*

- Treatment by a dentist assisted by AI
- Treatment by a very experienced dentist without AI
- Treatment by AI alone, if it were cheaper and faster
- Other: _____

Q20. AI makes half as many errors as a human. Whom would you trust with your treatment?*

- AI only
- A doctor supported by AI
- A human only
- Other: _____

Q21. AI will make dentists more...* (Multiple selections are possible.)

- Empathetic
- Lazy
- Precise
- Focused on the patient relationship
- Redundant
- Other: _____

(Note: Questions marked with an asterisk were mandatory in the original survey.)

Authors' contribution

Study design – M. Krysiak, K. Drobny

Data collection – K. Drobny

Data interpretation – M. Krysiak

Statistical analysis – M. Krysiak

Manuscript preparation – M. Krysiak, K. Drobny

Literature research – K. Drobny

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Primary pericardial mesothelioma: A cancer without prognosis? An epidemiological and clinical challenge

Pierwotny międzybłoniak osierdza: nowotwór bez rokowania? Wyzwanie epidemiologiczne i kliniczne

Estera Pazeł¹ , Michał Sikorski¹ , Michał Kapalka¹ , Michał Krawiec¹ ,
Grzegorz Hirnle² , Tomasz Hrapkowicz² 

¹Students' Scientific Club, Department of Cardiac, Vascular and Endovascular Surgery and Transplantology,
Faculty of Medical Sciences in Zabrze, Medical University of Silesia, Katowice, Poland

²Department of Cardiac, Vascular and Endovascular Surgery and Transplantology,
Faculty of Medical Sciences in Zabrze, Medical University of Silesia, Katowice, Poland

ABSTRACT

INTRODUCTION: Primary pericardial mesothelioma (PPM) is an exceptionally rare and aggressive malignancy, identified in less than 0.0022% of all autopsy examinations. Due to its nonspecific clinical course and symptom overlap with more common cardiopulmonary conditions, diagnosis is typically delayed and made at an advanced stage, significantly worsening prognosis. The median overall survival ranges from 6 to 10 months.

MATERIAL AND METHODS: A literature review was conducted using the PubMed, Medline, and Web of Science databases, covering PPM cases published between January 2015 and March 2025. The search was performed using the keywords “primary pericardial mesothelioma,” “pericardial mesothelioma,” and “malignant pericardial mesothelioma.” The collected data included clinical presentation, diagnostic methods, treatment approaches, and patient survival outcomes.

RESULTS: The clinical manifestations of PPM are nonspecific and commonly include pericardial effusion, chest pain, and symptoms of heart failure. Histopathological examination remains the diagnostic gold standard. Treatment strategies are primarily extrapolated from pleural mesothelioma protocols and involve chemotherapy (cisplatin + pemetrexed), surgery, and palliative care. Emerging therapies such as immunotherapy and anti-angiogenic agents (e.g., bevacizumab) have demonstrated potential efficacy.

CONCLUSIONS: PPM is characterized by diagnostic challenges, high mortality, and the absence of standardized treatment guidelines. Early diagnosis and a multimodal therapeutic approach may contribute to improved outcomes. Further prospective, multicenter studies are needed to develop effective treatment strategies for this rare malignancy.

KEYWORDS

treatment, survival, primary pericardial mesothelioma, rare heart tumor

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Address for correspondence: Estera Pazeł, Studenckie Koło Naukowe, Katedra i Klinika Kardiologii, Transplantologii, Chirurgii Naczyniowej i Endowaskulamej, Śląskie Centrum Chorób Serca, ul. M. Curie-Skłodowskiej 9, 41-800 Zabrze, tel. +48 519 163 857, e-mail: estera.pazek77@gmail.com



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STRESZCZENIE

WSTĘP: Pierwotny międzybłoniak osierdzia (*primary pericardial mesothelioma* – PPM) to wyjątkowo rzadki i agresywny nowotwór, wykrywany w mniej niż 0,0022% wszystkich badań autopsyjnych. Ze względu na niespecyficzny przebieg kliniczny oraz podobieństwo objawów do częstszych schorzeń sercowo-płucnych, jego rozpoznanie następuje zwykle w zaawansowanym stadium, co istotnie pogarsza rokowanie. Mediana przeżycia wynosi od 6 do 10 miesięcy.

MATERIAŁ I METODY: Przeprowadzono przegląd literatury dostępnej w bazach PubMed, Medline i Web of Science, obejmujący przypadki PPM opublikowane od stycznia 2015 r. do marca 2025 r. Wyszukiwanie przeprowadzono z użyciem słów kluczowych „primary pericardial mesothelioma”, „pericardial mesothelioma” i „malignant pericardial mesothelioma”. Analizowano dane dotyczące objawów, diagnostyki, leczenia oraz czasu przeżycia pacjentów.

WYNIKI: Obraz kliniczny PPM jest niespecyficzny i obejmuje wysięk osierdziowy, ból w klatce piersiowej oraz objawy niewydolności serca. Złotym standardem diagnostycznym pozostaje badanie histopatologiczne. Leczenie opiera się na schematach stosowanych w międzybłoniaku opłucnej i obejmuje chemioterapię (cisplatyna + pemetreksed), chirurgię oraz leczenie paliatywne. Nowe metody, takie jak immunoterapia czy inhibitory angiogenezy (np. bewacyzumab), wykazują potencjalną skuteczność.

WNIOSKI: PPM charakteryzuje się trudnościami diagnostycznymi, wysoką śmiertelnością i brakiem jednoznacznych wytycznych terapeutycznych. Wczesna diagnostyka oraz podejście wielomodalne mogą wpływać na poprawę rokowania. Potrzebne są dalsze badania prospektywne i wieloośrodkowe, aby opracować skuteczne strategie leczenia tej rzadkiej jednostki chorobowej.

SŁOWA KLUCZOWE

leczenie, przeżywalność, pierwotny międzybłoniak osierdzia, rzadki nowotwór serca

INTRODUCTION

Primary pericardial mesothelioma (PPM) is an exceptionally rare and aggressive malignancy, with an incidence of less than 0.0022%, as reported in a series of nearly 500,000 autopsies. It accounts for only 2–3% of all primary cardiac and pericardial tumors, ranking third in frequency after angiosarcoma (33%) and rhabdomyosarcoma (20%) [1]. Additionally, PPM represents an extremely uncommon subtype within the broader category of mesotheliomas, comprising approximately 0.7% of all diagnosed cases [2].

The clinical course of PPM is typically insidious, with nonspecific symptoms that contribute to delayed diagnosis, which is often established at an advanced stage or even postmortem. Common presentations include pericardial effusion, signs of constrictive pericarditis, and progressive heart failure, reflecting the tumor's local mass effect and pericardial involvement. Prognosis remains extremely poor, with a median survival ranging from 6–10 months following diagnosis [3]. Histopathological examination remains the cornerstone of diagnosis, given the lack of distinctive radiological or serological features. Despite reports suggesting associations with risk factors such as asbestos exposure, viral infections, ionizing radiation, immunodeficiency, and inherited susceptibility, the pathogenesis of PPM is still not fully understood. To date, no standardized treatment protocols have been established, and therapeutic decisions are primarily guided by evidence from individual case reports rather than prospective clinical trials.

MATERIAL AND METHODS

A literature review was conducted using PubMed, Medline, and Web of Science databases to identify published case reports and series of PPM from January 2015 to March 2025. Keywords used in the search included „primary pericardial mesothelioma,” „pericardial mesothelioma,” and „malignant pericardial mesothelioma.” Extracted data included patient demographics, clinical presentation, diagnostic methods, therapeutic interventions, and survival outcomes. Epidemiological data on incidence, mortality, and risk factors were also assessed.

DISCUSSION

Clinical manifestations of pericardial mesothelioma

PPM is an exceptionally rare neoplasm; nevertheless, it represents the most frequent type of primary malignant tumor arising in the pericardium [4]. Autopsy studies indicate that primary tumors of the heart occur in only 0.001%–0.28% of cases. In contrast, cardiac metastases are roughly 40 times more frequent than primary cardiac tumors [5]. The PPM population likely consisted primarily of men, with a median age of 46 years [6]. The pathogenesis of PPM remains poorly understood, and although sporadic associations with asbestos exposure have been reported, evidence supporting asbestos as an etiological factor – unlike in pleural mesothelioma – remains inconclusive [6,7]. Pericardial mesothe-

lioma may present as a localized solid mass, a sheet-like thickening of the pericardium, or diffuse infiltration of the pericardium and adjacent structures [8]. PPM is characterized by an insidious onset and a non-specific clinical picture, which often translates into a delay in diagnosis. It usually manifests with pericardial effusion, cardiac tamponade, or heart failure symptoms accompanied by chest pain, shortness of breath, fatigue, loss of appetite, and weight loss. These symptoms are nonspecific and can imitate the clinical presentation of various distinct disease entities. As the disease progresses, symptoms such as coughing, shallow breathing, or paradoxical pulse may emerge, accompanied by systemic manifestations including fever, night sweats, and general weakness [1]. The aggressiveness of the tumor quickly provokes involvement not only of the pericardium itself but also of the chest wall, diaphragm, and mediastinum, which is why lesions are sometimes detected only at an advanced stage, not amenable to radical treatment [9]. The diagnostic dilemma is that non-specific symptoms are easily confused with classic cardiac entities – such as the typical picture of tuberculous pericarditis or constrictive pericarditis, ischemic heart disease, or cardiomyopathy – which pays off with a high rate of erroneous clinical conclusions. Clinicians frequently overlook PPM, often attributing the patient's symptoms to more common conditions such as pericarditis or heart failure [2,10]. Imaging studies such as echocardiography, computed tomography, and magnetic resonance imaging often visualize heterogeneous thickening of the pericardium surrounding the heart with constrictive physiology [11]. Attempts to achieve local control face limitations due to tumor invasion, so most patients are diagnosed too late for therapy to be considered radical. Nonetheless, evidence indicates that early detection can substantially prolong survival beyond 6 months, particularly in patients suitable for surgical intervention and multimodality treatment [12].

Survival rate in pericardial mesothelioma in the context of other subtypes

There is no doubt that mesothelioma has a very poor prognosis, primarily because it is usually diagnosed at an advanced stage and there is a lack of breakthrough therapies. Five-year survival is less than 10%, and median survival rarely extends beyond 12 months. The vast majority of about 60%–70% of cases are malignant pleural mesothelioma (MPM), while the peritoneal mesothelioma accounts for about 30%–35%, and the pericardial form accounts for only 1%–2% [3,13].

Median overall survival (OS) for pleural mesothelioma oscillates around 9–12 months after diagnosis, although there are a few cases of patients achieving

significantly longer survival [14]. Early diagnosis, allowing the disease to be identified at an early stage, translates into better long-term outcomes. The 5-year survival rate in such cases is 7%–24%, while it is significantly lower for those diagnosed at a later stage [13]. Available trial results show that the peritoneal mesothelioma usually achieves slightly better results than the pleural form [3]. The median OS after first-line chemotherapy with platinum is about 16.6 months with a median progression-free time (PFS) of 7.3 months. Second-line treatment achieves a median OS of 16.9 months and PFS of about 3.2 months [15]. Nonetheless, the peritoneal mesothelioma remains relatively refractory to cytotoxic treatment, as median OS ranges between 6 and 12 months in the absence of intervention [16].

The median survival of PPM from symptom onset is under 6 months, reflecting a notably poor prognosis [17]. Even with therapeutic interventions (e.g., chemotherapy, radiotherapy, or surgery), the median survival time does not exceed 6–10 months, confirming the widespread belief in the eminently poor prognosis of this localization [18].

Advanced therapeutic strategies

To date, no standardized international therapeutic algorithm has been defined for the treatment of PPM, and the available clinical data are mainly based on heterogeneous single case reports. Currently, therapeutic protocols for the treatment of PPM draw patterns from the therapy used for pleural mesothelioma, and the treatment of pericardial mesothelioma includes a range of interventions, such as surgical procedures (pericardiectomy, resection), chemotherapy (pemetrexed in combination with cisplatin), radiation therapy (usually implemented as part of a trimodal strategy) and palliative care in advanced disease. Multimodal treatment – surgery, chemotherapy, and radiotherapy – is regarded as a potential standard in resectable pleural mesothelioma, but in PPM its efficacy remains uncertain due to a lack of prospective data and guidelines, and knowledge is based solely on case reports [3].

In PPM, surgical resection is a potential radical therapy provided that the disease process remains confined to the pericardium; however, invasion deep into the myocardium often pushes the possibility of surgery to the limits of effectiveness [19]. Although local surgery continues to be a mainstay of treatment, complete tumor explantation is proving difficult because the vast majority of patients are diagnosed at an already advanced stage, significantly limiting the chances of achieving an R0 resection [20].

It often proves necessary to implement a pericardial biopsy, pericardiectomy, or a massive diagnostic resection to confirm the diagnosis and assess the stage. Studies have shown no statistically significant

improvement in survival following surgical intervention, yet the procedure is still commonly performed to relieve patient symptoms by reducing discomfort caused by the tumor mass and improving hemodynamic function [21,22]. In cases of nodules of small size, without features of diffuse extension of the disease, resection procedures can serve a therapeutic function, while also contributing to the reduction of pericardial effusion and alleviation of symptoms associated with constriction of cardiac structures [10]. In the spectrum of surgical interventions, pericardiectomy stands out once pericardial fenestration, both procedures are performed to prevent recurrent fluid accumulation, which could consequently lead to cardiac tamponade [23].

A review of 103 published cases of PPM showed that only chemotherapy was associated with a statistically significant improvement in survival, while surgical treatment did not translate into a significant prognostic benefit. Special consideration should be given to the fact that, in the vast majority of chemotherapy cases, a combination of cisplatin and pemetrexed was used as the first-line treatment. These findings underscore the key role of systemic treatment in the therapeutic strategy of PPM and point to the limited efficacy of surgical approaches in monotherapy [21].

There is a lack of clear guidelines for second-line treatment of PPM after failure of first-line therapy based on platinum derivatives and pemetrexed.

However, a growing body of data points to the potential of bevacizumab, an angiogenesis inhibitor, as a valuable component of therapy. Efficacy in improving overall survival in pleural mesothelioma has recently been confirmed in clinical trials. In one case, the use of combination treatment with cisplatin, pemetrexed, and bevacizumab resulted in complete remission of clinical symptoms and satisfactory imaging results [24]. In a different case, bevacizumab was included as part of triple therapy, also alongside cisplatin and pemetrexed. Stabilization of the disease was confirmed by positron emission tomography-computed tomography (PET-CT) imaging, indicating a sustained response to the therapeutic regimen used. In light of the results obtained, bevacizumab appears to be a promising option that is also worth considering in secondary treatment strategies [25].

Recent scientific reports indicate an increasing role for immune checkpoint inhibitors (ICIs) in treating malignant mesothelioma, especially in patients with inoperable pleural forms [22]. Results from the CheckMate-743 trial showed a regimen based on nivolumab and ipilimumab to be more effective than standard chemotherapy (pemetrexed with cisplatin or carboplatin) [26]. The median survival was 18.1 months for the treatment group and 14.1 months for the control group. There was an obvious benefit for patients with the non-epithelial

subtype of pleural mesothelioma [27]. However, patients with primary pericardial symptoms or those with a history of malignant neoplasm that had not been in remission for at least 3 years were not eligible for the study [28]. Although the efficacy of immunotherapy in pericardial mesothelioma remains to be seen, these findings suggest potential applications for this rare tumor localization [29]. Despite the lack of unequivocal predictive markers, such as PD-L1 status or histologic type, the case of a patient with biphasic MPM and 30% PD-L1 expression who responded to nivolumab and ipilimumab therapy suggests that ICI may be effective in selected patients [30]. However, it should be emphasized, that the lack of clear predictive biomarkers and limited data on associations with chemotherapy in first-line treatment remain significant clinical challenges.

Also noteworthy is the case of a young patient in whom the use of immunotherapy with pembrolizumab in the second-line treatment, followed by atezolizumab, resulted in long-term disease stabilization and an impressive survival time of more than 4.5 years [25]. Moreover, a promising partial response was also reported in a 62-year-old patient, in whom the combination of pembrolizumab and chemotherapy translated into effective disease control maintained for 5 months [3]. Both cases highlight the potential of immunotherapeutic strategies in the treatment of selected patients, both in monotherapy and in combination regimens [30].

Radiation therapy for the treatment of PPM plays a marginal therapeutic role, due to both the biological resistance of the tumor to radiation and the limited clinical data supporting its efficacy [28]. Due to the rarity of PPM, the available information is mainly based on descriptive reports, and the lack of prospective studies prevents a clear assessment of the benefits of this type of intervention [31]. Accordingly, radiation therapy should be considered more as an adjunctive management, aimed at alleviating symptoms, promoting physical function, and preventing and treating potential complications [2].

Trimodal therapy in the treatment of pericardial mesothelioma

Trimodal therapy is a therapeutic approach that combines three different treatment modalities: surgery, adjuvant chemotherapy (most commonly cisplatin + pemetrexed), and complementary radiotherapy. In pleural mesothelioma, trimodal therapy translates into promising survival rates with reduced toxicity [32,33]. As demonstrated by Offin et al. [12], all eligible patients had prolonged disease control, highlighting the importance of the interdisciplinary team in selecting candidates for bolder, aggressive

therapeutic strategies. In the context of pericardial mesothelioma, this therapy can be used in selected patients with good performance status and limited disease spread. Prolonging survival and improving overall patient outcomes have become a concern in clinical practice. Literature data indicate that trimodal therapy produces better survival outcomes than single-modality treatment. The average survival time for patients receiving trimodal therapy was 70.3 months, compared with only 8.2 months for those who did not receive such treatment [12,32].

Despite the promising results, the inclusion of trimodal therapy in standard therapeutic guidelines is still hampered by the scarcity of multicenter, randomized trials with adequate statistical power.

The importance of platinum- and pemetrexed-based chemotherapy

Platinum-based chemotherapy, especially in combination with pemetrexed, is a key component of trimodality therapy. Studies clearly show that the introduction of chemotherapy translates into a significant survival benefit. A study by Kim et al. [34] showed that the median survival of patients treated with chemotherapy was 27 months (where it was only 1.5 months in the no-treatment group), and another analysis observed that the median survival time of patients receiving chemotherapy was 13 months, compared to only 0.5 months in the control group. The most pronounced therapeutic effects were achieved with regimens based on a combination of platinum plus pemetrexed or platinum alone [21,34].

According to literature reports and study results, nedaplatin, which is a second-generation platinum anticancer drug, shows comparable therapeutic efficacy to cisplatin, with a more favorable safety profile. It is characterized by higher water solubility, lower gastrointestinal toxicity, and reduced nephrotoxicity. In combination with pemetrexed, there was no significant myelotoxicity or recurrence of massive effusions, and patients showed high acceptance of therapy. This makes nedaplatin a valuable alternative to cisplatin, offering equivalent efficacy with a lower risk of side effects [35].

Palliative aspects of pericardial mesothelioma treatment

In advanced pericardial mesothelioma, comprehensive supportive care serves as an indispensable pillar of treatment, integrating radiotherapy, chemotherapy, and immunotherapy with precisely targeted surgical interventions, such as drainage of abundant pericardial effusions [28,36]. Such an integrated management model not only counteracts the most intractable

symptoms including pain with bone and neuropathic components, extreme cachexia, dyspnea, and psychological distress but also, through early implementation of palliative support, making it possible to prolong patients' survival while improving their quality of life [31,37,38].

Although palliative care is sometimes wrongly associated exclusively with the end stage of illness and a vision of helplessness, a legitimate shift in narrative focus exposing end-of-life care to targeting it as comprehensive therapeutic support overcoming resistance from patients and their loved ones and contributing to more comprehensive and coordinated medical care. Thus, a palliative therapeutic approach ceases to be considered an abandonment of the fight but becomes an integral part of the continuum of cancer treatment [38].

Given current recommendations, the timely integration of palliative and supportive care alongside causal therapy not only facilitates symptom control but also strengthens patients' motivation for further therapy. The holistic model of palliative care emphasizes multidimensional control of somatic suffering, psychosocial support for patients, and relief of pain and other symptoms of cachexia [38]. In the face of chronic pain of moderate severity, pharmacotherapy according to the World Health Organization analgesic ladder is recommended, using weaker opioids (e.g., codeine, tramadol), while in cases of severe pain, the implementation of stronger opioids is justified [31].

Future research, driven by the dynamic progress of oncologic medicine, will surely bring even more effective therapeutic options. Nonetheless, even today, multifaceted supportive care is an essential component of pericardial mesothelioma treatment.

CONCLUSIONS

PPM is extremely rare, presents with non-specific cardiopulmonary symptoms, and is usually diagnosed late, median survival is only 6–10 months. No standardized guidelines exist, so therapy is extrapolated from pleural mesothelioma: platinum plus pemetrexed remains first-line, with bevacizumab or ICIs showing promise in small series. Disease rarity, lack of biomarkers, and absence of prospective trials hinder evidence-based, individualized care, making early detection crucial for any curative multimodal strategy. Future priorities include better imaging, molecular profiling, immunotherapy integration, and routine early palliative care, all supported by multicenter collaboration to refine diagnosis and treatment and improve outcomes.

Authors' contribution

Study design – E. Pazeł

Data collection – M. Sikorski, M. Kapalka, M. Krawiec

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Bruxism in young adults (aged 18–25): The role of stress and other psychological factors

Bruksizm u młodych dorosłych (18–25 lat) – rola stresu i innych czynników psychologicznych

Piotr Ziobro¹ , Justyna Zientek¹ , Jakub Fiegler-Rudol¹ , Karolina Lau²

¹Students' Scientific Club, Department of Environmental Medicine and Epidemiology, Faculty of Medical Sciences in Zabrze,
Medical University of Silesia, Katowice, Poland

²Department of Environmental Medicine and Epidemiology, Faculty of Medical Sciences in Zabrze,
Medical University of Silesia, Katowice, Poland

ABSTRACT

Bruxism, defined as the involuntary activity of the masticatory muscles manifested by teeth grinding and clenching, represents a significant health concern among young adults. This study analyzes the etiopathogenesis, prevalence, and risk factors of bruxism in this age group, with particular emphasis on the role of psychological stress. A review of the literature reveals a significant correlation between high stress levels and increased bruxism symptoms, regardless of gender. Neurophysiological mechanisms underlying the disorder are discussed, including the involvement of the hypothalamic–pituitary–adrenal (HPA) axis and dopaminergic pathways. The study also highlights the utility of modern methods for monitoring bruxism-related behaviors, such as Ecological Momentary Assessment (EMA), which allows for real-time symptom tracking. Emphasis is placed on the importance of early diagnosis and a comprehensive therapeutic approach that addresses both the somatic and psychosocial aspects of bruxism. The findings underscore the need for further research on the interactions between stress, sleep, and pharmacotherapy in the context of effective prevention and treatment strategies.

KEYWORDS

bruxism, young adults, parafunction, dentistry, epidemiology

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Address for correspondence: Piotr Ziobro, Studenckie Koło Naukowe, Katedra i Zakład Medycyny i Epidemiologii Środowiskowej, Wydział Nauk Medycznych w Zabrzu SUM, ul. Jordana 19, 41-808 Zabrze, tel. +48 32 272 28 47, e-mail: s86367@365.sum.edu.pl



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STRESZCZENIE

Bruksizm, definiowany jako mimowolna aktywność mięśni żucia przejawiająca się zgrzytaniem i zaciskaniem zębów, stanowi istotny problem zdrowotny u młodych dorosłych. Niniejsze opracowanie analizuje etiopatogenezę, częstość występowania oraz czynniki ryzyka bruksizmu w tej grupie wiekowej, ze szczególnym uwzględnieniem roli stresu psychologicznego. Przegląd literatury wskazuje na istotną korelację między wysokim poziomem stresu a nasileniem objawów bruksizmu, niezależnie od płci. Omówiono neurofizjologiczne mechanizmy leżące u podstaw zaburzenia, w tym udział osi podwzgórze–przysadka–nadnercza (*hypothalamic–pituitary–adrenal* – HPA) oraz szlaków dopaminergicznych. W pracy podkreślono także przydatność nowoczesnych metod monitorowania zachowań związanych z bruksizmem, takich jak Ecological Momentary Assessment (EMA), umożliwiających śledzenie objawów w czasie rzeczywistym. Szczególny nacisk położono na znaczenie wczesnej diagnostyki oraz kompleksowego podejścia terapeutycznego, obejmującego zarówno aspekty somatyczne, jak i psychospołeczne bruksizmu. Wyniki podkreślają potrzebę dalszych badań nad interakcjami między stresem, snem a farmakoterapią w kontekście skutecznej profilaktyki i strategii leczenia.

SŁOWA KLUCZOWE

bruksizm, młodzi dorośli, parafunkcje, stomatologia, epidemiologia

Introduction

According to the definition by the American Academy of Orofacial Pain, bruxism is described as “diurnal or nocturnal parafunctional activities including clenching, bracing, grinding, and gnashing of the teeth” [1]. Depending on the time of occurrence, bruxism is classified into nocturnal bruxism, which occurs during sleep, and awake bruxism, which occurs during wakefulness. Nocturnal bruxism refers to masticatory muscle activity during sleep, which may be rhythmic (phasic) or non-rhythmic (tonic) in nature. Awake bruxism involves masticatory muscle activity during wakefulness, characterized by repetitive or sustained tooth contact, and tension or thrusting of the mandible [1].

Bruksizm manifests as excessive activity of the masticatory muscles, leading to teeth grinding, clenching, and ultimately to the wear of healthy dental tissues and alterations in the stomatognathic system [1,2].

According to the literature, the prevalence of bruxism does not differ significantly based on nationality or race [2]. A definitive difference in prevalence between genders has also not been clearly established [3]. However, some authors have reported a higher prevalence of awake bruxism or both types of bruxism in women [4]. The presence of bruxism may change over a person’s lifetime depending on age. It is more common in young adults and less frequent among older individuals [4]. If left untreated, bruxism can lead to numerous complications that affect not only oral health but also the patient’s overall health. Early diagnosis and the implementation of appropriate treatment methods such as relaxation splints, physical therapy, or stress reduction can effectively reduce the risk of serious consequences associated with this condition [1].

The aim of this study is to highlight the growing prevalence and clinical significance of bruxism, with a particular focus on why it most commonly affects young individuals.

Etiology of bruxism

Psychological stress is one of the most commonly cited etiological factors of bruxism, as it can significantly influence behavior and the functioning of the nervous system, thereby affecting masticatory muscle activity. As a result of chronic stress, the body may respond to emotional tension with excessive muscular activity, leading to teeth clenching [5]. Such reactions can occur both during the day and at night, and their intensity often depends on the level of stress and the individual’s physiological response [6]. Numerous studies have demonstrated the significant role of neurological factors in the etiology of bruxism. Bruxism, particularly the nocturnal form, is considered a disorder of central nervous system regulation [7]. There is impaired control over the masticatory muscles through mechanisms such as:

- alterations in dopaminergic and serotonergic transmission
- hyperactivity of neurons in the red nucleus, substantia nigra, and thalamus
- micro-arousals during sleep that coincide with muscle activity.

Dopamine plays a key role in all these processes as a neurotransmitter responsible for motor control. Dysfunctions in dopaminergic pathways can lead to excessive muscle activity [7].

Secondary triggering factors may include sleep disorders such as obstructive sleep apnea (OSA) or parasomnias. Nocturnal bruxism often coexists with: OSA, as a defensive mechanism, parasomnias, such as sleepwalking or nightmares, sleep fragmentation, which increases susceptibility to involuntary muscle contractions [7]. Other potential contributing factors include anatomical abnormalities in the temporomandibular joint, genetic predispositions, and pharmacological influences, especially the use of certain psychotropic medications, such as selective serotonin reuptake inhibitors (SSRIs) [8]. Some medications, particularly psychotropic drugs, may induce bruxism



as a side effect: SSRIs (e.g., fluoxetine, paroxetine), neuroleptics and antidepressants. It is believed that their effect on the serotonergic system disrupts dopaminergic balance, thereby enhancing involuntary activity of the masticatory muscles [9].

Impact of stress on the genesis of bruxism

Stress is widely accepted as a contributing factor in the pathogenesis of bruxism. A more precise understanding of this phenomenon requires consideration of distress and allostatic load [10]. Distress refers to the body's negative response to stress, arising from being overwhelmed by excessive demands, experienced losses, or perceived threats. It leads to harmful consequences, resulting in both physical and psychological disorders [10,11]. Allostatic load refers to the cumulative burden of chronic stress and adverse life experiences, stemming from the interaction of various physiological systems operating at different levels of activity. When environmental challenges exceed an individual's ability to cope, allostatic overload occurs. In humans, daily behaviors such as teeth clenching, bruxism, or nail-biting are most frequently observed in individuals experiencing panic states [11]. These mechanisms indicate a strong link between stress and parafunctional activity in the stomatognathic system. Studies suggest that masticatory dysfunction and associated occlusal disharmony, such as bite elevation or tooth loss, can activate the hypothalamic–pituitary–adrenal (HPA) axis. Via the hypothalamus (corticotropin-releasing hormone – CRH), pituitary gland (adrenocorticotrophic hormone – ACTH), and adrenal glands, glucocorticoids (GC) are released into the bloodstream. Elevated levels of corticosterone in blood and urine can persist for a long time. Cortisol enhances sympathetic nervous system responses, leading to increased muscle tension, including in the masticatory muscles such as the masseters. This results in excessive tension and heightened activity during clenching or grinding of the teeth. Prolonged grinding causes enamel wear, tooth fractures, and crown damage. Additionally, prolonged muscle tension can lead to fatigue, pain, and over time, structural changes including reduced mobility of the temporomandibular joint (TMJ).

Moreover, CRH also activates another neuronal pathway: the sympatho-adrenal axis through stimulation of the locus coeruleus (LC), further increasing sympathetic activation [12]. Chronic stress and excessive HPA axis activity are associated with dysfunction of 5-hydroxytryptamine (5-HT) serotonin receptors in the hippocampus, resembling changes observed in individuals with suicidal tendencies. Activation of the lateral habenula (LHb), which regulates dopamine and serotonin, also plays a significant role. Occlusal disharmony may stimulate

the LHb, disrupting its homeostatic inhibitory functions and promoting the development of depression, sleep disturbances, and chronic pain. During sleep, individuals under chronic stress may experience episodes of bruxism due to the nervous system's inability to suppress sympathetic dominance. Neuroimaging and ophthalmologic studies have shown neurodegenerative changes in both the brain and retina of patients with sleep bruxism, including a reduction in axonal thickness and retinal ganglion cell layer. These changes resemble those seen in individuals with major depressive disorder, underscoring a potential link between neurodegeneration and bruxism.

Impact of stress on facial muscle modulation

The normal hormonal response to stress may be altered due to damage to the ventral tegmental area (VTA), indicating that the dopaminergic system influences the functioning of the HPA axis [13]. Brain regions such as the ventral subiculum (vSub) of the hippocampus and the basolateral amygdala (BLA) exert modulatory but opposing effects on dopaminergic neuron activity in the VTA. These neurons are typically kept in a resting state through hyperpolarization [14]. Moreover, the regulation of mastication involves a two-neuron pathway, in which serotonergic neurons from the raphe nuclei connect synaptically with dopaminergic neurons in the VTA. Central bruxism may occur in two opposing states: in hyperdopaminergic conditions, such as those induced by amphetamines or levodopa (L-dopa), and in cholinergic deficiency; as well as in hypodopaminergic states, which appear in dysfunctions of the extrapyramidal system [15]. Certain neurological disorders, such as Parkinson's or Huntington's disease, or pharmacological agents like SSRIs, which alter 5-HT receptor function, may also cause secondary bruxism [15]. Abnormal functioning of 5-HT₂ receptors also plays a significant role in the pathogenesis of bruxism. This leads to a paradox in treatment: despite the involvement of 5-HT₂, 5-HT₁ receptor agonists are commonly used as first-line treatment. Changes in presynaptic 5-HT₁ and 5-HT₂ receptor function, or their interactions, can disrupt the mesocortical dopaminergic pathway, which is crucial for controlling involuntary muscle movements [15]. Stress affects serotonin receptor function in a region-dependent manner. It reduces the number of 5-HT_{1A} receptors in the hippocampus, while increasing their expression in the cerebral cortex [16]. In contrast, 5-HT_{2A} receptors, present in motor, sensory, and spinal nuclei of the trigeminal nerve and other areas, appear to remain unaffected by stress [17]. Reduced inhibition of trigeminal motor neurons may lead to overactivation of the masseter muscle, which is a key disturbance in bruxism and promotes



involuntary jaw movements. Susceptibility to social stress appears to be linked to suppression of the mesocortical system, observed in both bruxism patients and those with temporomandibular disorders (TMDs). Interestingly, long-term stress responses differ by gender, as the dopaminergic system shows sex-specific morphological and molecular changes. Stress leads to remodeling of the mesocortical and mesolimbic dopaminergic pathways, and a significant decrease in dopaminergic activity in the VTA [18].

Research on bruxism, stress, and anxiety in university students

In 2021, a study was conducted involving 328 dental students aged 21–41 of both sexes at the Faculty of Dentistry of the University of Medicine and Pharmacy in Craiova [19]. The aim was to determine the prevalence of probable bruxism, explore its relationship with stress and anxiety, and highlight symptoms related to temporomandibular disorders. All participants were in very good health, with no systemic illnesses or medications. The gender distribution was: 212 women (64.63%) and 116 men (35.36%). The study found that 39.33% (129 participants; 80 women, 49 men) reported symptoms of bruxism. There was no significant correlation between gender and self-reported bruxism ($\phi = 0.044$; $\chi^2(1) = 0.638$; $p = 0.424$). The Cochran-Armitage trend test showed no significant linear relationship between age groups and bruxism prevalence ($p = 0.227$). Among the 129 participants: 21 reported sleep bruxism (SB) only, 89 reported awake bruxism (AB) only, 19 experienced both SB and AB. In the group of 40 participants with SB (alone or combined), the most commonly reported symptoms were teeth grinding noticed by a partner and morning masticatory muscle fatigue. In total, 68.29% (224 participants) reported experiencing stress. Of these, 49.55% (111 participants; 77 women, 34 men) also reported bruxism, while 50.45% (113 participants) did not. Bruxism occurred in 88.8% of stressed individuals, compared to 56.78% of those without stress, indicating a moderate, statistically significant association between stress and bruxism ($\phi = 0.307$; $\chi^2(1) = 30.950$; $p < 0.0005$). No correlation was found between stress and gender or age ($p > 0.05$). Significant differences were observed in the frequency of bruxism episodes depending on stress level ($p < 0.0005$). Post hoc analysis showed that individuals with higher stress levels (“very high,” “extensive”) reported more frequent bruxism episodes (“sometimes,” “often”) than those with lower stress levels (“none,” “mild”), who reported such episodes less frequently [19,20].

Gender differences in prevalence

There are conflicting findings regarding gender differences in the prevalence of bruxism. Some studies suggest that women may be more prone to bruxism due to a greater susceptibility to psychological stress. Other research, however, indicates no significant gender differences, or even a higher risk among men, particularly in relation to bruxism associated with physical exertion and muscle tension [21]. In epidemiological studies conducted by Ohayon et al. [22], it was observed that bruxism is more frequently diagnosed in younger age groups, particularly among young adults aged 20–40 years. Both awake and sleep bruxism are present in this population. Researchers did not find any significant gender differences in the prevalence of bruxism.

Age-related prevalence of bruxism

Bruxism can occur across various age groups, but its frequency changes with age. In children, especially those in preschool and early school age, this phenomenon is relatively common. In many cases, it is a transient issue associated with the development of the stomatognathic system, tooth eruption, or stress. The peak prevalence of bruxism, classified as a parafunctional behavior, occurs among young adults aged 18–40 years, and is linked to increased emotional tension, stress, and lifestyle factors [23]. Stress is widespread among young people and stems from dynamic life changes, social pressure, uncertainty about the future, and the fast pace of modern life, all of which may lead to chronic emotional strain. In this age group, bruxism often requires treatment, as it may cause tooth damage and TMDs. This is confirmed by findings from Bracci et al. [24] from the University of Padua and the University of Siena, who studied awake bruxism in healthy young adults using a mobile app for real-time self-reporting (Ecological Momentary Assessment – EMA, also known as the Experience Sampling Method – ESM). In the study, 46 dental students used a smartphone app that sent 15 random alerts per day for one week, prompting them to report their current jaw muscle condition by tapping an icon on the screen: relaxed jaw muscles, tooth contact, teeth clenching, teeth grinding, jaw clenching without tooth contact (so-called bracing). The average frequency of relaxed jaw muscles, as a percentage of responses over 7 days, was 71.7%. The most frequently reported behaviors were tooth contact (14.5%) and jaw bracing (10.0%). No significant gender differences were found. While there were individual differences among participants, the overall behavior frequency showed moderate day-to-day



variability, with a low coefficient of variation for the “relaxed jaw muscles” state (0.44). On an individual level, the most commonly reported behavior was tooth contact, reported at least once daily by 39.1%–52.2% of participants. During the 7-day observation period, the average real-time reporting frequency among healthy young adults was 28.3%. The low daily variability in the frequency of relaxed jaw muscles suggests that EMA is a reliable tool for studying the epidemiology of oral behaviors. This study introduced EMA into the analysis of awake bruxism and provided data on behavior frequency in young adults, which may serve as a reference point for populations at risk or with clinical consequences.

After the age of 50, the prevalence of bruxism significantly decreases, likely due to natural dental changes, reduced muscle tone, and a lower physiological stress response. It is worth noting that the intensity of bruxism can fluctuate throughout life, and its occurrence is closely tied to individual predispositions and external factors.

Bruxism in young adults and stress

Young adults today experience elevated levels of stress due to a unique combination of societal, economic, and psychological pressures that are more intense than those faced by previous generations. This heightened stress is increasingly recognized as a contributing factor in the onset and exacerbation of bruxism.

Economic instability

Today’s young adults face a more difficult financial reality than many previous generations. Even those with higher education often struggle to secure stable employment that enables independent living. Key issues include the high cost of living and the burden of student loans.

In countries such as the United States, the United Kingdom, and even parts of Europe, young people frequently graduate with significant debt. Repaying these loans may take years, delaying life milestones like buying a home, starting a family, or investing in personal growth [25]. In addition, everyday living expenses – rent, food, and transportation – are rising faster than wages. In many major cities, young adults are forced to live with roommates or remain with their parents due to financial constraints.

Slimmen et al. [26] conducted a study at a University of Applied Sciences between November 16, 2020, and January 18, 2021, examining variables such as psychological well-being, perceived stress, academic pressure, financial pressure, family pressure, extracurricular obligations, coping style, self-esteem, loneliness, and personality traits. A total of 875 university students (37.2% male, 62.3% female, mean

age 21.6) participated. Perceived stress had a strong negative association with mental well-being ($b = -0.848$, $p < .001$; $r = -0.667$, $p < .01$), explaining 45% of the variance. Academic pressure ($b = -8.014$, $p < .01$), family pressure ($b = -3.189$, $p < .01$), extracurricular pressure ($b = -3.032$, $p < .01$), and financial pressure ($b = -2.041$, $p < .01$) negatively impacted well-being. Notably, academic and family pressure showed direct effects even after accounting for perceived stress. Interaction effects were also found between perceived stress and coping strategies, as well as emotional stability. The findings highlight how financial insecurity and the burden of early adulthood debt significantly influence the mental well-being of young people.

Social media pressure

Social media plays a dominant role in the lives of young adults. While these platforms can offer connection, inspiration, and entertainment, they increasingly contribute to psychological strain. The main stressors related to social media include comparison culture, fear of missing out (FOMO), and dependency on external validation [27].

Platforms like Instagram, TikTok, and Facebook present highly curated, idealized portrayals of life, career achievements, exotic vacations, perfect appearances, and flawless relationships. As a result, many young individuals feel inadequate or “behind” in life. Constant exposure to images of parties or social events they are not part of can foster feelings of exclusion and loneliness, which in turn intensifies stress and the compulsion to conform socially [27].

Moreover, the content promoted by algorithms is often visually and emotionally stimulating, creating an illusion that most people lead joyful, successful lives. In reality, these are carefully staged moments, and real-life struggles are hidden. For young people entering adulthood, this contrast can lead to disappointment and cognitive dissonance when their actual experiences fall short of online expectations [28].

Information overload

In the digital age, young people are bombarded daily with massive amounts of information. This phenomenon, termed *information overload*, refers to the situation in which the volume of incoming data exceeds an individual’s capacity to process, analyze, and use it meaningfully [29].

Technology now provides greater access to information than ever before. However, evidence shows that human cognitive capacity for absorbing and storing information is limited. Constant exposure, especially to negative content like wars, crises, and diseases, can trigger chronic stress and anxiety. This



in turn activates physiological responses such as muscle tension, emotional hypersensitivity, and sleep disturbances [30,31].

A growing and increasingly prevalent threat linked to information overload is the spread of so-called “fake news”. The psychological impact of misinformation has become a major focus in social psychology and neurobiology. In today’s digital media environment, where information spreads rapidly, false reports can have real and harmful consequences for mental health particularly among young adults. Fake news often takes the form of sensationalized and dramatic headlines about public health threats, social unrest, or economic collapse, all of which contribute to heightened emotional tension, stress, and even anxiety disorders [32,33].

Discussion

This study confirms that bruxism in young adults is a multifactorial disorder strongly influenced by psychological stress, neurophysiological dysregulation, and modern lifestyle pressures. The findings align with previous research highlighting a significant correlation between elevated stress levels and both awake and sleep bruxism, especially in populations aged 18 to 25 [5,19]. Notably, stress activates the HPA axis, and chronic stimulation of this pathway can increase masticatory muscle tone, contributing to parafunctional activity [10,12]. Neurobiological models suggest a key role of dopaminergic and serotonergic dysregulation in central bruxism, which is further supported by alterations in receptor function under chronic stress conditions [16,18]. The impact of SSRIs also warrants attention, as medications such as fluoxetine and paroxetine have been associated with bruxism by disrupting the dopaminergic-serotonergic balance [8,15]. This pharmacologically induced form of bruxism highlights the importance of considering iatrogenic factors when diagnosing or treating young patients. Furthermore, social stressors, particularly those related to digital environments, have emerged as significant contributors to psychological overload. The constant exposure to idealized portrayals on social media platforms fosters social comparison and self-doubt, which in turn may exacerbate stress-induced muscle activity and bruxism episodes [27,31].

Evidence indicates that social media fatigue and emotional dysregulation are strongly linked, especially among students and digital natives [30,32]. The role of EMA in studying oral behaviors offers new insights. The real-time monitoring approach allows for precise behavioral tracking, demonstrating a 28.3% daily frequency of non-relaxed jaw activity among young adults, without significant gender differences [24]. This is consistent with other epidemiological reports showing that both sexes are affected, although some studies suggest women may report higher rates of awake bruxism [4,22]. Our results also point to significant neurophysiological overlap between bruxism and stress-related disorders. For example, structural changes in areas such as the VTA, hippocampus, and amygdala due to prolonged stress can alter dopamine modulation and contribute to heightened muscle reactivity [13,14]. Such findings correspond to those in neuropsychiatry, where bruxism is increasingly viewed as a somatic manifestation of emotional and cognitive dysregulation. In addition, the role of misinformation and cognitive overload in the digital age must not be underestimated. As observed by Liu et al. [32] and Ali Adeeb and Mirhoseini [33], the psychological burden caused by exposure to alarming or false content, especially during sensitive periods like early adulthood, may lead to chronic sympathetic activation and sleep fragmentation, key mechanisms underlying nocturnal bruxism. Taken together, the evidence reinforces the need for a multidisciplinary approach to managing bruxism in young adults. Dentists, mental health professionals, and primary care providers must collaborate in developing therapeutic strategies that address both the physiological and psychosocial components of this disorder. Preventive measures should also incorporate media literacy and stress-reduction programs for students, given the observed link between academic pressure and bruxism severity [26]. Future research should focus on longitudinal assessments using tools like EMA to better map behavior patterns, explore gender-specific neurobiological mechanisms, and evaluate the therapeutic effects of combined cognitive-behavioral and occlusal interventions. Moreover, exploring how allostatic load contributes to the persistence of bruxism beyond young adulthood could offer new perspectives for early intervention strategies [11,20].

Authors’ contribution

Study design – P. Ziobro, J. Zientek

Data collection – P. Ziobro, J. Fiegler-Rudol, J. Zientek

Manuscript preparation – P. Ziobro, J. Zientek, K. Lau

Literature research – P. Ziobro, J. Fiegler-Rudol, J. Zientek

Final approval of the version to be published – K. Lau



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Experiences of discriminatory behavior in reproductive care: Preliminary study findings

Doświadczenia dyskryminacyjnego traktowania w opiece reprodukcyjnej – wstępne wyniki badania

Martyna Szymańska¹ , Piotr Romaniuk² 

¹Students' Scientific Club, Department of Health Policy, Faculty of Public Health in Bytom,
Medical University of Silesia, Katowice, Poland

²Department of Health Policy, Faculty of Public Health in Bytom, Medical University of Silesia, Katowice, Poland

ABSTRACT

INTRODUCTION: Discrimination in healthcare often stems from biases related to gender, age, race, or disability. Among the vulnerable groups are women accessing reproductive care, such as prenatal testing, infertility treatment and perinatal care. These patients may experience various forms of unequal treatment, ranging from a lack of respect to the denial of medical procedures. Despite existing recommendations and legal regulations, discrimination remains a global issue. The aim of this study was to examine women's experiences of discrimination while accessing reproductive healthcare services.

MATERIAL AND METHODS: The study was conducted both online and in-person using a validated proprietary questionnaire. Inclusion criteria were: female gender, age ≥ 18 years, and use of reproductive healthcare services within the past 10 years. The study group consisted of 401 women. Data collection took place from June 1, 2024, to February 1, 2025. Statistical analysis was performed using Statistica 13.3, with statistical significance set at $p < 0.05$.

RESULTS: The majority of participants rated their experiences positively, however 28% reported instances of discrimination by medical staff. The most common issues included the use of inappropriate language, ignoring questions, or facial expressions indicating reluctance or disapproval. Additionally, 20% of respondents observed discriminatory behavior toward other female patients.

CONCLUSIONS: Despite many positive evaluations, the study revealed the presence of discrimination in reproductive healthcare. Both personal experiences and observations of such situations influence women's perception of the healthcare system and their sensitivity to inequality.

KEYWORDS

sexism, women, women's health, reproductive health

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Address for correspondence: Martyna Szymańska, Studenckie Koło Naukowe, Zakład Polityki Zdrowotnej, Wydział Zdrowia Publicznego w Bytomiu SUM, ul. Piekarska 18, 41-902 Bytom, tel. +48 32 397 65 21, e-mail: martyna.szymanska@sum.edu.pl



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STRESZCZENIE

WSTĘP: Dyskryminacja w ochronie zdrowia często wynika z uprzedzeń związanych z płcią, wiekiem, rasą czy niepełnosprawnością. Na dyskryminację narażone są również kobiety korzystające z opieki reprodukcyjnej, obejmującej m.in. dostęp do badań prenatalnych, leczenia niepłodności i opieki okołoporodowej. Pacjentki te mogą doświadczać różnych form nierównego traktowania – od braku szacunku po odmowę wykonania procedur. Mimo obowiązujących rekomendacji i regulacji prawnych problem dyskryminacji ma charakter globalny. Celem badania było poznanie doświadczeń kobiet w zakresie dyskryminacji w trakcie korzystania ze świadczeń opieki reprodukcyjnej.

MATERIAŁ I METODY: Badanie przeprowadzono online i stacjonarnie z wykorzystaniem autorskiego, zwalidowanego kwestionariusza. Kryteriami włączenia były: płeć żeńska, wiek ≥ 18 lat oraz korzystanie z opieki reprodukcyjnej w ciągu ostatnich 10 lat. Grupę badawczą stanowiło 401 kobiet. Badanie trwało od 1 czerwca 2024 r. do 1 lutego 2025 r. Analizę przeprowadzono w programie Statistica 13.3, przyjmując istotność statystyczną dla $p < 0,05$.

WYNIKI: Większość uczestniczek oceniła swoje doświadczenia pozytywnie, jednak 28% zgłosiło przejawy dyskryminacji ze strony personelu medycznego. Do najczęstszych należały używanie niestosownego języka, ignorowanie pytań lub mimika wskazująca na niechęć lub dezaprobatę. Dodatkowo 20% badanych zaobserwowało zachowania dyskryminacyjne wobec innych pacjentek.

WNIOSEK: Mimo wielu pozytywnych ocen badanie ujawniło również przypadki dyskryminacji w opiece reprodukcyjnej. Zarówno osobiste doświadczenia dyskryminacji, jak i obserwacje takich sytuacji wpływają na postrzeganie systemu ochrony zdrowia przez kobiety oraz na ich wrażliwość na nierówności.

SŁOWA KLUCZOWE

seksizm, kobiety, zdrowie kobiety, zdrowie reprodukcyjne

INTRODUCTION

The concept of discrimination refers to less favorable treatment based on gender, age, race, ethnic origin, religion, belief system, sexual orientation, or disability, in comparison to the treatment of another person in a similar situation [1]. According to Link and Phelan [2], discrimination is the final component of the stigmatization process, which begins with labeling human differences and associating them with negative stereotypes. Discrimination can occur on an interpersonal or direct level (i.e., in human relationships and everyday life) as well as on a structural or indirect level (i.e., through laws and regulations, policies, and constitutional practices) [2]. Discrimination against individuals in the healthcare sector and other settings stems from beliefs and prejudices related to gender, age, ethnic origin, disability, and other factors [3].

Reproductive care is directly related to two concepts: sexual and reproductive health. Sexual health is defined as a state of physical, emotional, mental, and social well-being in relation to sexuality, and not merely the absence of disease or dysfunction. This aspect of human health requires a positive and respectful approach to sexuality, as well as the possibility of having satisfying and safe sexual experiences, free from discrimination and coercion. Achieving sexual health requires respect for and protection of the sexual rights of all individuals [4]. Reproductive health is a state of complete physical, mental, and social wellbeing, not merely the absence of disease or infirmity, in all matters relating to the reproductive system, its functions, and processes.

Furthermore, according to the World Health Organization (WHO), the concept of reproductive health implies that individuals can lead satisfying and safe sexual lives, have the capability to reproduce, and have the freedom to decide if, when, and how often to have children [5].

WHO has identified five key areas of reproductive and sexual health. These include:

- improving prenatal, childbirth, postpartum, and neonatal care
- ensuring high-quality family planning services
- eliminating unsafe abortions that pose a risk to health and life
- combating sexually transmitted infections, including HIV, reproductive tract infections, cervical cancer, and other gynecological conditions
- promoting sexual health [6].

Access to reproductive and sexual healthcare can have a significant impact on people's lives around the world. Achieving full reproductive and sexual health is an essential component of the highest attainable standard of mental and physical health. Access to such healthcare also supports human dignity and overall well-being [4]. The concept of reproductive care may encompass a wide range of health services and procedures, including access to contraception, prenatal testing, treatment of all conditions related to the female reproductive system, infertility treatment, pregnancy termination for various reasons, as well as childbirth and perinatal care [7,8].

Discriminatory behaviors toward women using reproductive care services manifest in various ways and may affect different groups of women. Women belonging to the LGBT (lesbian, gay, bisexual,



transgender) minority also experience prejudice from healthcare professionals in the context of reproductive care. Discriminatory attitudes among medical staff may include, for example, limited access to infertility treatment for same-sex couples or the refusal to perform gynecological examinations for transgender women [8]. Discriminatory behaviors toward recipients of medical services may vary depending on the type of healthcare professional involved and the setting in which the services are provided. Women receiving perinatal care may experience medical interventions to which they did not give consent and which lack medical justification, performed with the aim of shortening the duration of labor [9,10]. Outdated and non-recommended procedures are still being used in maternity wards, which can harm patients and lead to iatrogenic complications, for example, placing the laboring woman in the lithotomy position. Such practices may be perceived as a form of discrimination resulting from the improper delivery of healthcare services that fail to consider the needs, comfort, and choices of patients [10]. Other forms of discrimination related to reproductive care include delays in providing medical assistance, refusal to administer pain relief, lack of respect for patients' privacy, detaining women in medical facilities, and other similar practices [11,12].

Patients receiving reproductive care should remain in constant contact with the medical staff, who are obligated to provide accurate and comprehensive information. Smooth communication between doctors, nurses, midwives, and the patient is crucial to ensuring high-quality reproductive care, regardless of the healthcare setting. Unfortunately, in many cases, medical personnel ignore patients' questions or provide inconsistent and even insufficient answers [13,14]. There are situations in which patients encounter insults, verbal abuse, or comments intended to reprimand or hurt their feelings. In some cases, they are victims of verbal violence. Specialists often assume that women's health conditions result from their lifestyle rather than from various diseases or disorders. The use of unprofessional and offensive language during interactions with patients, as well as dismissing the health problems they present, is also problematic [15]. Discrimination in access to reproductive healthcare services can also occur at the institutional and legal levels. According to Article 68 of the Constitution of the Republic of Poland, "everyone has the right to health protection, and public authorities are obliged to provide special healthcare, including for pregnant women" [16]. Health security and its stability are inseparably linked to the right to health protection, as both concepts are connected to the personal dignity of the individual [17].

The aim of the study was to assess women's experiences of discrimination while using reproductive healthcare services.

MATERIAL AND METHODS

The study was conducted using a dual approach, both in-person and remotely, through a custom questionnaire. The data was collected using a survey questionnaire administered both in a traditional paper-based format (paper and pen interview – PAPI) and online computer-assisted web interview – CAWI), which enabled access to a diverse group of respondents. The online version of the questionnaire was shared on social media platforms such as Facebook and Instagram. Submission of a completed questionnaire was considered equivalent to providing informed consent to participate in the study. Inclusion criteria were: age ≥ 18 years, identifying as female, and having used reproductive healthcare services within the past 10 years. In this study, two sampling methods were employed: random sampling and convenience sampling. A total of 401 women participated in the study. The research was conducted between June 1, 2024, and February 1, 2025. Data analysis was performed using Statistica for Windows version 13.3, applying descriptive statistics and comparative tests (chi-square test). Results were considered statistically significant at a p-value of < 0.05 . It is important to note that the study sample was not representative at the national level.

RESULTS

The demographic profile of the respondents, including age, place of residence, education level, relationship status, sexual orientation, and number of children, is presented in Table I. The average age of respondents was 27 years. The largest group of respondents lived in cities with populations over 100,000. In terms of education, the most commonly reported level was secondary education (53%). Notably, 13% of respondents identified as non-heteronormative. Additionally, the majority of respondents did not have children (76%).

Participants assessed their past experiences with reproductive healthcare on a scale from 1 (very poor) to 5 (very good). The most frequently selected rating was 3 ($n = 158$), followed closely by a rating of 4 ($n = 145$). Significantly fewer respondents chose ratings of 2 and 5 (45 and 41, respectively). The least frequently selected rating was 1 ($n = 12$).

Participants were also asked which healthcare specialists they had consulted over the past 10 years.



This was a multiple-choice question. The majority of respondents reported using the services of a gynecologist or gynecological clinic (63%). Seventeen percent had visited an endocrinologist or an endocrinology clinic, and 11% had seen an obstetrician-gynecologist. A smaller proportion of women had consulted a dietitian specializing in endocrine disorders (3%) or a urogynecological physiotherapist (3%).

Respondents were asked about the reasons for receiving reproductive healthcare. This was a multiple-choice question. The most frequently indicated reasons were hormonal disorders ($n = 89$) and other health problems ($n = 93$). Commonly reported reasons also included hypothyroidism or hyperthyroidism ($n = 85$), polycystic ovary syndrome (PCOS; $n = 55$), and perinatal care ($n = 53$). Other reasons included endometriosis (35 responses), insulin resistance (32 responses), and other endocrine disorders

(30 responses). The responses are presented in Table II.

Participants were asked whether they had experienced discriminatory behavior from healthcare professionals. The vast majority of women reported no such experiences. However, 28% of respondents answered affirmatively.

Women who reported experiencing discriminatory behavior were asked to specify the types of behaviors they encountered. This was a multiple-choice question. The most commonly reported experience was facial expressions indicating aversion or disgust (70 responses). Other frequently reported behaviors included ignoring questions or requests (50 responses), use of offensive language, insults, or name-calling (46 responses), refusal to provide medication or anesthesia (12 responses), and performing medical procedures without consent or prior information (11 responses). The responses are presented in Table III.

Table I. Demographic characteristics of respondents

Sociodemographic data		Total $n = 401$ (100%)
Age groups	18–27 years	286 (71%)
	28–37 years	57 (14%)
	38–47 years	38 (9%)
	48–57 years	14 (3%)
	58 years and older	6 (1%)
Place of residence	Village	47 (12%)
	City under 20,000 inhabitants	38 (9%)
	City of 20,000–100,000 inhabitants	105 (26%)
	City over 100,000 inhabitants	211 (53%)
Education level	Vocational	5 (1%)
	Secondary	212 (53%)
	Higher	181 (45%)
	Postgraduate (PhD, habilitation)	3 (1%)
Relationship status	Single	143 (36%)
	In a partnership	162 (40%)
	Married	81 (20%)
	Widowed	3 (1%)
	Divorced	12 (3%)
Sexual orientation	Heterosexual	347 (87%)
	Homosexual	11 (3%)
	Bisexual	41 (10%)
	Other	2 (1%)
Number of children	No children	305 (76%)
	One child	46 (11%)
	Two children	38 (9%)
	Three or more children	12 (3%)

**Table II.** Reasons for receiving reproductive healthcare

Response	Number of responses n = 585 (100%)
Infertility, fertility disorders	18 (3%)
Difficulty maintaining pregnancy, miscarriages	16 (3%)
Hypothyroidism or hyperthyroidism	85 (15%)
Ovarian dysfunction (hypofunction or hyperfunction)	13 (2%)
Polycystic ovary syndrome (PCOS)	55 (9%)
Other endocrine disorders	30 (5%)
Hormonal disorders (e.g., hyperandrogenism, hyperestrogenism)	89 (15%)
Endometriosis	35 (6%)
Insulin resistance	32 (5%)
Diabetes	12 (2%)
Excess body weight	39 (7%)
Reproductive organ cancers	15 (3%)
Perinatal care	53 (9%)
Other	93 (16%)

Table III. Discriminatory behaviors experienced by respondents

Experienced behavior	Number of responses n = 209 (100%)
Facial expressions suggesting aversion or disgust	70 (33%)
Ignoring questions or requests	50 (24%)
Offensive language, insults or name-calling	46 (22%)
Refusal to provide medication (e.g., painkillers, sleeping pills) or anesthesia	12 (6%)
Performing medical procedures without consent or prior information (e.g., episiotomy)	11 (5%)
Refusal to perform specific procedures	7 (3%)
Pushing, shoving, or other behavior suggestive of physical abuse	6 (3%)
Other	4 (2%)
Deliberate delay in performing procedures	3 (1%)

The respondents were asked to indicate specific medical professions whose representatives behaved inappropriately. The most frequently mentioned were doctors and nurses – these responses were marked 87 and 56 times, respectively. The obtained results are presented in Table IV.

Table IV. Medical professions identified as source of inappropriate behavior

Profession	Number of responses n = 165 (100%)
Doctor	87 (53%)
Nurse	56 (34%)
Midwife	15 (9%)
Dietitian	3 (2%)
Psychologist	2 (1%)
Physiotherapist	1 (1%)
Other	1 (1%)

All participants in the study were asked whether they had witnessed situations in which another patient experienced discriminatory treatment. As many as 20% of the respondents confirmed that they had observed such behavior towards other women. Women who had witnessed discrimination against other patients were then asked to answer the next question, what undesirable situations they had observed. This was a multiple-choice question. The most frequently noticed situations were: facial expressions suggesting reluctance or disgust (n = 54), ignoring questions or requests (n = 40), and offensive language, insults, and name-calling (n = 36). The remaining responses are presented in Table V.

A statistical analysis was conducted to examine the relationship between respondents' evaluations of their reproductive healthcare experiences and their exposure to discriminatory behavior. The results indicate a very strong statistical association between



responses to these two questions ($p = 0.00001$). Detailed results of the analysis are presented in Table VI.

Table VII presents the results of an analysis examining the relationship between responses to the question: Do you believe there is a difference in the quality of reproductive healthcare services depending on the patient's gender?, and two grouped variables: number of children and age. The statistical analysis revealed significant associations between these variables.

The next part of the questionnaire included questions presented in table form, using a 5-point scale where 1 meant "strongly disagree" and 5 meant "strongly

agree." Most respondents believe that women are discriminated against in healthcare ($n = 175$), although a significant number of participants selected the neutral option 3, meaning "no opinion" ($n = 109$). Additionally, the majority of participants ($n = 314$) believe that women with conditions affecting their physical appearance are more likely to experience stigmatization. A large portion of the surveyed women think that women do not have more difficulty accessing necessary medical services compared to men ($n = 161$). A clear majority of respondents agreed with the statement that medical staff downplays the pain experienced by female patients ($n = 267$). All the responses obtained are presented in Table VIII.

Table V. Discriminatory behaviors observed by respondents towards other patients

Experienced behavior	Number of responses $n = 172$ (100%)
Facial expressions suggesting aversion or disgust	54 (31%)
Ignoring questions or requests	40 (23%)
Offensive language, insults or name-calling	36 (21%)
Refusal to provide medication (e.g., painkillers, sleeping pills) or anesthesia	15 (9%)
Performing medical procedures without consent or prior information (e.g., episiotomy)	9 (5%)
Pushing, shoving, or other behavior suggestive of physical abuse	7 (4%)
Refusal to perform specific procedures	5 (3%)
Deliberate delay in performing procedures	5 (3%)
Other	1 (1%)

Table VI. Relationship between the evaluation of reproductive healthcare experiences and exposure to discrimination by healthcare workers

Have you experienced discriminatory behavior from healthcare workers?	Response to the question: On a scale of 1 to 5, how would you rate your reproductive healthcare experiences so far?					Total	chi ² -value	p-value
	1	2	3	4	5			
No	8 (3%)	20 (7%)	109 (38%)	118 (41%)	35 (12%)	290 (100%)	27.97	0.00001
Yes	4 (4%)	25 (23%)	49 (44%)	27 (24%)	6 (5%)	111 (100%)		
Total	12 (3%)	45 (11%)	158 (39%)	145 (36%)	41 (10%)	401 (100%)		

Table VII. Associations between the variables "number of children" and "age" and the perception of gender-based differences in reproductive healthcare quality

Number of children	Response to the question: Do you believe there is a difference in the quality of reproductive healthcare services depending on the patient's gender?					Total	chi ² -value	p-value
	1	2	3	4	5			
None	20 (7%)	47 (15%)	130 (43%)	70 (23%)	38 (12%)	305 (100%)	16.88	0.00204
1 child	4 (9%)	8 (17%)	26 (57%)	5 (11%)	3 (7%)	46 (100%)		
2 children	2 (5%)	12 (32%)	22 (58%)	2 (5%)	0 (0%)	38 (100%)		
3 or more children	2 (17%)	2 (17%)	5 (42%)	2 (17%)	1 (8%)	12 (100%)		
Total	28 (7%)	69 (17%)	183 (46%)	79 (20%)	42 (10%)	401 (100%)		



cd. Tabeli VII

Age group (years)	Response to the question: Do you believe there is a difference in the quality of reproductive healthcare services depending on the patient's gender?					Total	chi ² -value	p-value
	1	2	3	4	5			
18–27	17 (6%)	44 (15%)	119 (42%)	68 (24%)	38 (13%)	286 (100%)	35.30	0.00361
28–37	4 (7%)	14 (25%)	30 (53%)	7 (12%)	2 (4%)	57 (100%)		
38–47	6 (16%)	6 (16%)	22 (58%)	4 (11%)	0 (0%)	38 (100%)		
48–57	1 (7%)	4 (29%)	9 (64%)	0 (0%)	0 (0%)	14 (100%)		
58 and older	0 (0%)	1 (17%)	3 (50%)	0 (0%)	2 (33%)	6 (100%)		
Total	28 (7%)	69 (17%)	183 (46%)	79 (20%)	42 (10%)	401 (100%)		

Table VIII. Questions conducted using a 5-point scale

Questions	Number of responses 1	Number of responses 2	Number of responses 3	Number of responses 4	Number of responses 5
Do you believe that women are discriminated against in healthcare?	31	86	109	121	54
Do you believe that women suffering from conditions affecting physical appearance (e.g., PCOS and other hormonal disorders, obesity) are more likely to experience stigmatization?	11	21	55	202	121
Do you believe that women have more difficulty accessing necessary medical services (e.g., quick diagnosis, administration of anesthesia before painful procedures) compared to men?	55	106	108	77	55
Do you believe that women have more difficulty accessing necessary medical services (e.g., during childbirth, curettage, IUD insertion)?	15	53	66	149	118
Do you believe that reproductive care for women struggling with fertility disorders is properly organised?	62	118	181	33	7
Do you believe that reproductive care for women after miscarriage or stillbirth is properly organised?	98	120	158	18	7
Do you believe that women have equal access to information about reproductive care?	47	118	127	77	32
Do you believe that women have access to contraception (e.g., hormonal contraception, morning-after pill, IUD insertion)?	71	101	52	134	43
Do you believe there is a difference in the quality of reproductive healthcare services depending on the patient's gender?	28	69	183	79	42

PCOS – polycystic ovary syndrome; IUD – intrauterine device

DISCUSSION

The phenomenon of discrimination against patients using various healthcare services poses a serious challenge that requires a multifaceted and in-depth analysis. Conducting research that takes into account the specific characteristics of different patient groups

(e.g., gender, race, ethnic background) is particularly important because experiencing discriminatory attitudes and behaviors can negatively affect health through psychological and physiological stress responses, as well as through adverse health behaviors that lead to a deterioration in overall health [18]. To counteract discrimination against women, it is necessary to document experiences among broad



groups of women in various areas of life. Participants in the original study were asked to rate their reproductive healthcare experiences so far using a 5-point scale, where 1 meant “very bad” and 5 meant “very good.” The highest number of responses were recorded at levels 3 ($n = 158$) and 4 ($n = 145$), which may indicate a moderate level of satisfaction. At the same time, these results point to areas that require improvement in the quality of care provided.

The respondents were asked whether they had encountered discriminatory behavior from healthcare workers. Twenty-seven percent of the women surveyed answered affirmatively. Similar results were reported in a study conducted by SteelFisher et al. [18], in which one in five women reported experiencing gender-based discrimination during a visit to a doctor or healthcare facility. Comparable findings were also presented in a study by Nong et al. [19], where 21.4% of participants admitted to experiencing discriminatory attitudes and behaviors within the healthcare system. Furthermore, this study showed that women were particularly vulnerable to discriminatory behavior.

Respondents who reported experiencing discriminatory behavior in the study were asked to answer several follow-up questions, including those regarding the nature of these behaviors and the professions of the staff members who committed them. The most frequently reported forms of discrimination by patients were: facial expressions from the staff suggesting reluctance or disgust ($n = 70$), ignoring requests or questions ($n = 50$), and the use of offensive language and insults ($n = 46$). In the original study, the highest number of reports concerned doctors ($n = 87$), nurses ($n = 56$), and midwives ($n = 15$). Different results were presented in a study by Lansky et al. [11], which focused on the experiences of pregnant women. There, the most common forms of discrimination were performing medical interventions without patient consent or after consent given based on incomplete or distorted information, verbal abuse, and physical violence. Available research indicates that discriminatory behaviors can be carried out by various professional groups, including doctors, nurses, and midwives. It is important to emphasize that the presence of such attitudes is not always a result of faulty beliefs or prejudices. It may stem from a sense of superiority, the culture prevailing in healthcare facilities, or the overburdening of medical staff [11,19,20,21].

All participants had the opportunity to answer whether they had witnessed cases of discrimination against other patients using reproductive healthcare services. Twenty percent of respondents answered affirmatively. Women who reported witnessing discrimination

most often observed situations where another patient was met with facial expressions from staff suggesting reluctance or disgust ($n = 54$), ignoring of questions or requests ($n = 40$), the use of offensive language or insults ($n = 36$), as well as refusal to administer medications such as painkillers, sleeping aids, or anesthesia ($n = 15$). It is worth noting that the percentage of participants who personally experienced discrimination is comparable to the percentage of those who witnessed it.

The next part of the questionnaire included questions presented in table form, using a 5-point scale. The purpose of this section was to examine the participants’ views and opinions regarding discrimination in the healthcare sector. The study participants were asked whether they believed that women are discriminated against in the healthcare system. A total of 175 respondents selected either 4 (“agree”) or 5 (“strongly agree”) on a 5-point scale. A significant portion of the respondents chose the neutral option, 3, which indicates “no opinion.” The results may be partially influenced by the demographic and social characteristics of the study group. In addition to an increased risk of gender-based discrimination, young women, individuals with excess body weight, as well as those with lower socioeconomic status, may be particularly vulnerable to unfavorable treatment when interacting with the healthcare system. Furthermore, women who have experienced or witnessed discriminatory behavior in the context of reproductive care may be more sensitive to such attitudes and may have developed a specific worldview, which can affect how they interpret and assess situations within the healthcare system [17,22].

Some medical conditions, either directly or indirectly related to endocrinology or gynecology, may affect a person’s physical appearance. This group of conditions includes obesity, which results in visible accumulation of body fat, as well as hormonal disorders and gynecological diseases such as PCOS and associated conditions like hyperandrogenism or hypertestosteronemia, which can lead to symptoms such as hormonal acne or hirsutism (excessive male-pattern hair growth) [23,24]. The respondents were asked to express their opinion on the statement: Are women suffering from conditions that affect their physical appearance (e.g., PCOS, hormonal disorders, obesity) more likely to experience stigmatization? The vast majority of participants ($n = 314$) agreed with this statement (responses 4 and 5). This result may stem from the respondents’ personal experiences or situations they have witnessed. Research suggests that individuals with conditions affecting physical appearance may be particularly vulnerable to discrimination and stigmatization. It is worth noting



that such attitudes often arise from prejudice, gender stereotypes, or a lack of understanding about the causes and characteristics of the given condition [13,25].

This study encountered several limitations related to the surveyed group. First and foremost, all questionnaires were entered into a single database, which made it impossible to conduct analyses distinguishing between responses collected online and those collected in person. As a result, it was not possible to provide an in depth description of the findings that accounted for potential differences between participants who took part in the study remotely versus those who did so in person, differences that could have potentially influenced the responses obtained. Another limitation was the difficulty in finding comparable studies of a similar nature. Due to the specific focus of this research – namely, gender-based discrimination in healthcare – most of the available literature addressed multi-factorial discrimination, such as that involving both gender and race. This made it challenging to directly relate the findings of this study to those of other authors.

CONCLUSIONS

1. The majority of the women surveyed assessed their experiences with reproductive healthcare as positive.
2. Despite the overall positive evaluation, the collected data clearly suggest the presence of certain instances of discrimination within reproductive care.
3. The most frequently reported forms of discrimination included facial expressions from medical staff suggesting reluctance or disgust, the use of offensive language, and ignoring patients' questions or requests.
4. The perception of discriminatory behavior among participants in the study was shaped by factors such as age, number of children, sexual orientation, and declared relationship status.
5. There is a need to undertake in depth research that will provide better insight into the nature of experienced discrimination and the mechanisms behind its emergence.

Authors' contribution

Study design – M. Szymańska, P. Romaniuk

Data collection – M. Szymańska

Data interpretation – M. Szymańska

Statistical analysis – M. Szymańska

Manuscript preparation – M. Szymańska, P. Romaniuk

Literature research – M. Szymańska

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The presence of antibiotics in food and the consequences for human health

Obecność antybiotyków w żywności i jej konsekwencje dla zdrowia człowieka

Dominika Nicz¹ , Gabriela Myslek¹ , Katarzyna Lis¹ , Janusz Kasperczyk²

¹Students' Scientific Club, Department of Environmental Medicine and Epidemiology, Faculty of Medical Sciences in Zabrze, Medical University of Silesia, Katowice, Poland

²Department of Environmental Medicine and Epidemiology, Faculty of Medical Sciences in Zabrze, Medical University of Silesia, Katowice, Poland

ABSTRACT

Modern technological advancements are intensifying activities across numerous sectors, including human medicine, veterinary medicine, and agriculture. These fields are closely interconnected, notably through the widespread use of antibiotics. These antimicrobial agents, employed in the treatment of both humans and animals, are increasingly associated with significant public health and environmental concerns. The excessive and unregulated use of antibiotics in livestock production, combined with the application of manure and other animal-derived products as agricultural fertilizers, contributes to the accumulation of these substances in the environment and their subsequent entry into the food chain. Consequently, antibiotic residues may be detected in food products. Prolonged exposure to subtherapeutic doses of antibiotics can promote the development of bacterial resistance (antimicrobial resistance), as well as induce various adverse health effects, including hepatotoxicity, allergic reactions, and potential carcinogenicity. In light of these risks, the establishment of maximum residue limits (MRLs) and the implementation of guidelines for the prudent use of antibiotics in animal husbandry and agriculture are essential for safeguarding public health. The presence of antibiotic residues in food represents a significant threat to public health, primarily due to its role in accelerating antimicrobial resistance. Therefore, the judicious use of these substances in agriculture and livestock farming, supported by robust regulatory frameworks and effective sanitary monitoring throughout the food production chain, is of paramount importance.

KEYWORDS

antibiotics, antimicrobial resistance, environmental contamination, food safety, veterinary medicine

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Address for correspondence: Dominika Nicz, Studenckie Koło Naukowe, Katedra i Zakład Medycyny i Epidemiologii Środowiskowej, Wydział Nauk Medycznych w Zabrzu SUM, ul. Jordana 19, 41-808 Zabrze, tel. +48 32 272 28 47, e-mail: s83435@365.sum.edu.pl



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STRESZCZENIE

Współczesny rozwój technologiczny przyczynia się do intensyfikacji działań w wielu dziedzinach, w tym w medycynie, weterynarii i rolnictwie. Obszary te są ze sobą ściśle powiązane, m.in. poprzez powszechne zastosowanie antybiotyków. Preparaty te (substancje bakteriobójcze), wykorzystywane zarówno w leczeniu ludzi, jak i zwierząt, coraz częściej stanowią źródło problemów zdrowotnych i środowiskowych. Nadmierne i niekontrolowane stosowanie antybiotyków w hodowli, a także nawożenie pól uprawnych obornikiem i innymi produktami pochodzenia zwierzęcego, prowadzi do ich akumulacji w środowisku i przenikania do łańcucha pokarmowego. W konsekwencji w żywności mogą występować pozostałości substancji przeciwdrobnoustrojowych. Długotrwała ekspozycja na niskie dawki antybiotyków może skutkować rozwojem oporności bakterii na leczenie (antybiotykooporność), a także wywoływać inne działania niepożądane, takie jak hepatotoksyczność, reakcje alergiczne czy potencjalne działanie rakotwórcze. Z tego względu kluczowe znaczenie mają regulacje prawne określające dopuszczalne poziomy pozostałości (*maximum residue limits* – MRLs) oraz zasady racjonalnego stosowania antybiotyków w produkcji zwierzęcej i rolniczej, których celem jest ochrona zdrowia publicznego. Obecność antybiotyków w żywności stanowi istotne zagrożenie dla zdrowia publicznego, głównie poprzez nasilenie zjawiska antybiotykooporności. Dlatego kluczowe znaczenie ma racjonalne stosowanie tych substancji w hodowli i rolnictwie, a także skuteczna kontrola legislacyjna i sanitarna na wszystkich etapach produkcji żywności.

SŁOWA KLUCZOWE

antybiotyki, antybiotykooporność, zanieczyszczenie środowiska, bezpieczeństwo żywności, medycyna weterynaryjna

INTRODUCTION

Antibiotics are a group of critically important drugs for both humans and animals, as demonstrated by their widespread use in various sectors such as agriculture, aquaculture, human medicine, animal nutrition, and livestock farming [1]. They are defined as substances capable of killing or inhibiting the growth of bacteria [2]. Veterinary medicines – antibiotics among them – play a key role in animal health and feed production and in maintaining the health of livestock, with estimates indicating that in 2015, approximately 80% of food-producing animals underwent veterinary treatment at various stages of their lives, and sometimes throughout their entire rearing period [2]. Over a 12-year period, the European Surveillance of Veterinary Antimicrobial Consumption (ESVAC) project led to a reduction of more than 50% in the sales of veterinary antibiotics in Europe, demonstrating that effective animal treatment can be achieved while substantially limiting antibiotic use [3].

Globally, the consumption of these agents by livestock is estimated to be nearly twice human consumption. Antibiotics are used not only for therapeutic or prophylactic purposes but also as growth promoters – especially in countries where such practices are still permitted [4].

Given the cross-sectoral use of antibiotics, a coordinated response is essential. In response to the escalating threat of antimicrobial resistance (AMR), the international community has increasingly endorsed the One Health approach. This interdisciplinary framework recognises the intrinsic interconnectedness of human, animal, and environmental health, and underscores the necessity of coordinated action among medical professionals, veterinarians, public health experts, and environmental scientists [5].

AMR is widely regarded as a prototypical One Health challenge, given its capacity to transcend species barriers and environmental boundaries, thereby posing a significant threat to global public health [6].

Since the late 1940s, antibiotics have been routinely used in animal husbandry, and since then, an increase in human infections caused by antibiotic-resistant bacterial strains has been observed [7]. The improper use of antibiotics in livestock farming can lead to the presence of antibiotic residues in food products of animal origin, such as milk, eggs, or meat, posing a potential health risk to consumers [8]. According to scientific literature, the presence of such substances in food can contribute to the selection and spread of antibiotic-resistant bacteria, facilitate their transmission to humans, and cause adverse effects such as AMR, allergic reactions, and toxic effects on the human body [1]. The World Health Organization (WHO), the American Medical Association, and the American Public Health Association have called for a ban on the use of antibiotics for growth promotion and have established guidelines aimed at restricting such practices [9]. As a result, the presence of drug residues, including antibiotics, in food at levels exceeding the maximum residue limit (MRL) set by international regulatory bodies is considered a violation of current legislation. Moreover, strict adherence to withdrawal periods, as well as physico-chemical analyses to confirm that the concentrations of active substances or their metabolites do not exceed established thresholds, is required before a food product can be approved for market distribution [8]. Food contaminated with antibiotic residues above the MRLs poses a serious threat to human health and is therefore a significant and ongoing public health concern [1]. This review article aims to discuss the pathways through which antibiotic residues can enter food at various stages of production and to summarize



the consequences for human health. It will also outline the regulations governing the use of antibiotics and medicinal substances by food producers.

MATERIAL AND METHODS

This study is a review based on an analysis of the available scientific literature, reports from international institutions, and current legislation concerning the presence of antibiotics in food and their impact on human health. A comprehensive search was conducted using databases such as PubMed, ScienceDirect, Scopus, Google Scholar, and the European legal database EUR-Lex to obtain reliable and up-to-date information. Priority was given to publications from the last decade; however, older sources that significantly contributed to the development of the field were also included when substantively justified. The literature search was conducted in English between January and April 2025. Keywords used during the search included, but were not limited to: “antibiotic residues,” “veterinary antibiotics,” “food-producing animals,” “antibiotic resistance,” “human health,” and “food contamination.” These terms were selected to best reflect the thematic scope of the study, focusing on antibiotic residues from animal production, their presence in food, and their potential impact on human health and the development of microbial resistance. The search yielded 231 results. The selection of sources was based on their recency, scientific credibility (including peer-reviewed status), relevance to the topic – such as the presence of antibiotics in food, their health implications, or legal frameworks – and the availability of full-text articles. Both primary empirical studies and review articles were analysed, along with reports from key institutions including WHO, the European Food Safety Authority (EFSA), the European Centre for Disease Prevention and Control (ECDC), and the United States (US) Food and Drug Administration (FDA). A separate section focused on the analysis of legislation currently in force within the European Union (EU) and selected non-EU countries. This included regulations of the European Parliament and Council, national monitoring programmes, and documents regarding residue limits for pharmacologically active substances in food. The collected data were qualitatively analysed and organised according to thematic categories, with particular attention to their implications for public health and the environment. It should be noted, however, that the data presented in the literature are not always consistent. Significant differences between publications are often attributable to geographical context – such as epidemiological data from countries at different stages of economic development. These differences may

pertain both to data collection methodologies and to actual levels of risk. Sector-specific variation is also relevant, as data from the pork, poultry, or dairy sectors can differ substantially. Inconsistencies may also stem from divergent definitions and classifications used across studies. Despite prioritising the most recent sources, it is important to acknowledge that not all included publications are fully up to date due to the rapidly evolving nature of legislation.

DISCUSSION

Pathways of antibiotic entry into the food chain

The preservation of food with additional substances represents an innovation in the food industry [10]. Moreover, food products may become contaminated during production due to environmental chemicals, residues from animal husbandry, or intentionally added substances [11]. Antibiotics, whether naturally occurring or synthetically introduced during processing, can also be deliberately incorporated into food as preservatives. Their primary function is to inhibit spoilage and extend the shelf life of food products [12].

Animal husbandry

One indirect route through which antibiotics may enter the food chain is their use during the animal husbandry stage. This sector is regulated by numerous standards that address animal welfare, product safety and quality, production efficiency, and public health protection [2]. All relevant guidelines for livestock breeders are outlined in the Animal Health Code [13] whereas food safety and the use of veterinary medicinal products in the EU are governed by regulations such as Regulation (EU) 2019/6 and Implementing Regulation (EU) 2022/1286, which aim to restrict the prophylactic use of antimicrobials in groups of animals. Unfortunately, many of these regulations are disregarded in large-scale production of pigs, cattle, and poultry, where the primary focus is often on maximizing productivity and profit, frequently at the expense of animal welfare and consumer safety [14,15]. In intensive farming systems, animals are often kept in environments that severely restrict their movement, preventing the expression of natural, species-specific behaviors. Additionally, animals are commonly subjected to painful zootechnical procedures, such as beak trimming in poultry, tail docking in pigs, and castration without anesthesia [16]. These practices contribute to elevated stress levels, suppressed immune function, and increased susceptibility to disease. Under such conditions, infectious diseases spread rapidly among densely confined animal



populations [17], necessitating the routine administration of drugs, typically via feed or drinking water [18,19].

Veterinary drugs include antimicrobials (such as antibiotics), growth promoters, sedatives, anticoccidials, non-steroidal anti-inflammatory drugs (NSAIDs), and anthelmintics [20]. The highest use of antimicrobials is observed in pig (45%), poultry (33%), and cattle (22%) farming, as confirmed by the FDA's 2023 report [21,22]. In a 2019 study conducted in Lebanon, Jammoul and El Darra [23] found residues of antibiotics in chicken meat samples, including tetracycline (17%), oxytetracycline (10%), doxycycline (3.75%), amoxicillin (18%), ampicillin (15%), and penicillin (13%). These findings demonstrate that antibiotics commonly used in animal husbandry can accumulate in animal tissues, ultimately reaching consumers through food. Due to the risks associated with this phenomenon, the EU banned the use of antibiotics for growth promotion in 2006. Studies on poultry meat have shown that countries such as Germany, Lithuania, and Poland have not fully complied with relevant veterinary drug regulations [24]. This is noteworthy given that the 2022 EFSA report indicated an overall non-compliance rate of only 0.18% across all sample types. Further research by Akhmet et al. [25] that meat imported from Russia, Ukraine, and the US contained antibiotic residues exceeding MRLs. Improper antibiotic use in livestock not only leads to tissue accumulation but also affects animal-derived products such as milk and eggs [26]. This is primarily due to the failure to observe appropriate withdrawal periods and incomplete veterinary record-keeping [27,28,29]. The extent of antibiotic accumulation in tissues varies depending on the pharmacological and pharmacokinetic properties of the drugs and the animal species involved [30]. Factors contributing to the exceedance of permitted levels in food products include farmers' lack of knowledge, intentional non-compliance, and insufficient regulatory oversight [31]. Moreover, many developing countries lack effective monitoring systems to detect pharmacological contaminants in food [32].

The development of aquaculture is also associated with significant antibiotic use [33]. In this sector, pharmacological treatments are administered orally, by injection, or added directly to water bodies [34]. Studies have confirmed the presence of antibiotic residues in aquatic environments, including both water and sediment samples, indicating environmental contamination [35,36,37].

Such intensive use of antibiotics in livestock and aquaculture contributes to their accumulation in final food products.

Crop production

As one of the most dynamic ecosystems on Earth, soil plays a crucial role in the cycling of substances [33]. It serves as a key substrate in agriculture, where it is intensively utilized and periodically requires nutrient enrichment. A common organic fertilizer used for this purpose is manure, which supplies plants with essential nutrients [38]. However, manure, although organic, often contains pharmaceutical residues stemming from veterinary drug use. This contamination results from the bioavailability of antibiotics in livestock, which can range from 30% to 90%, depending on the specific compound and the animal species to which it was administered [39].

Following metabolism, antibiotics are primarily excreted via urine and feces, subsequently entering the soil through the application of animal manure. From there, these residues may leach into groundwater and surface water systems [40,41]. A 2019 study conducted by Chinese researchers confirmed that antibiotic resistance can develop in soil microbiota within just two months of cattle manure application [42].

Each class of antibiotics behaves differently in the environment. For example, sulfonamides are most frequently detected in surface and groundwater, whereas tetracyclines and fluoroquinolones exhibit long half-lives in soil, where they may persist for several months [43]. The presence of antibiotics in soil can lead to the development of antimicrobial-resistant bacteria, that can colonize crops and subsequently enter the human gastrointestinal tract [44]. Several studies have demonstrated that bacteria can acquire resistance due to the application of animal-derived manure in agricultural production [45,46,47,48,49].

Mulchandani et al. [50] emphasize that in countries such as China, Brazil, India, and the United States, the contamination of agricultural land with zoonotic manure is considered a major contributor to the spread of antibiotic resistance genes. Additionally, areas characterized by intensive livestock farming tend to experience reduced soil and groundwater quality due to antibiotic contamination, with negative effects on microbial biodiversity [51]. While the commercial use of compost products offers numerous benefits, it may also facilitate the dissemination of resistance genes in the environment. However, composting presents an opportunity for the biodegradation of pharmaceuticals, which could help mitigate the risk of spreading antibiotic resistance [52,53].

It is also notably that plants are capable of absorbing antibiotic residues from manure applied to soil [54].



These residues may disrupt normal plant growth by inducing abiotic stress [55,56,57]. Furthermore, the consumption of vegetables and fruits grown in areas where sewage or animal manure has been applied can lead to the ingestion of antibiotics accumulated in plant tissues [58]. The extent of accumulation and the specific plant organs affected depend on the type of antibiotic involved [59]. A 2022 study found that tetracyclines exhibited the highest concentrations among common classes of antibiotics in plants, with the greatest accumulation observed in root systems [60,61,62].

Additives in processed food products

Following the production process, food products must be appropriately packaged. At this stage, food-contact packaging increasingly incorporates antimicrobial materials to extend shelf life [63,64]. Various strategies are employed to achieve antimicrobial activity, including the addition of sachets containing volatile agents, embedding active substances into biopolymers, coating or grafting agents onto polymer surfaces, and the use of internal polymers or antimicrobial pads [65]. In light of growing bacterial resistance to antibiotics, packaging technologies increasingly rely on natural and synthetic bactericidal agents, such as preservatives and silver nanoparticles, to inhibit microbial growth [66,67,68]. Antibiotics may also be incorporated into halloysite nanotubes, which offer enhanced thermal stability, extended product shelf life, and controlled antimicrobial release [69,70].

Additionally, bacteriocins – antimicrobial peptides naturally synthesized by bacteria – are utilized in food preservation, including within packaging systems [71]. Nisin, a well-characterized bacteriocin, has been officially approved as a natural food-grade antimicrobial additive. It is effective against various foodborne pathogens, such as *Listeria monocytogenes*, as well as a wide range of Gram-positive bacteria [12,72,73,74,75].

However, antibiotic-impregnated packaging remains at the experimental stage and is not approved for use in food applications in either the EU or the US.

Adverse health effects

As previously discussed, veterinary pharmaceuticals – particularly antimicrobial agents – are frequently detected in animal-derived food products. The persistence of these compounds is governed by multiple factors, including their pharmacodynamic and pharmacokinetic properties and the subsequent physicochemical processing of animal tissues. However, the principal driver is the improper use of antimicrobials and non-compliance with mandated withdrawal periods. Alarming, recent years have

seen a marked increase in food-borne infections caused by AMR pathogens, underscoring the direct link between antimicrobial use in livestock and the spread of resistance mechanisms among bacterial populations [30,34].

The WHO has identified AMR as one of the most critical threats to global health security in the 21st century [76]. Although the direct toxicological impact of antimicrobial residues in food on human physiology remains inadequately elucidated, the potential for horizontal gene transfer of resistance determinants via the food chain is now recognized as a major public-health hazard [77].

From a regulatory standpoint, residues that remain within the MRLs are considered toxicologically acceptable. This classification is based on lifetime-exposure models that have shown no significant adverse effects in humans [78]. In contrast, concentrations exceeding established MRLs are linked to a spectrum of health risks, including the promotion of AMR, immunological hypersensitivity reactions, genotoxicity, nephrotoxicity, hepatocellular injury, disruption of intestinal-microbiota homeostasis, and reproductive toxicity. Hematotoxic effects and a potential role in carcinogenesis have also been proposed in the context of chronic exposure [2,30,34]. Because most antimicrobials are excreted in urine, they can reach aquatic environments via municipal wastewater systems and effluent discharge, thereby contributing to environmental contamination. This is particularly relevant to aquaculture, where antimicrobials are routinely administered for prophylaxis and therapy. Environmental exposure, combined with the therapeutic use, facilitates bioaccumulation in fish tissues. Human consumption of such products – especially when eaten raw – may therefore constitute an additional, often underestimated, route of exposure. In an experimental study, Herman et al. [79] assessed common culinary techniques for their ability to reduce antimicrobial-residue levels in fish. Thermal processing – boiling, frying, or baking for 10 minutes – achieved only moderate reductions; complete degradation was not possible [2,34].

Antibiotic resistance

The emergence and spread of antibiotic-resistant bacteria represent the most critical consequence of antimicrobial overuse. Projections suggest that by 2050, deaths attributable to AMR infections could exceed those caused by cancer [2,34,80]. This scenario portends higher infection rates, more frequent and prolonged hospital stays, increased mortality, and substantially greater healthcare expenditures.

Remarkably, even minimal environmental concentrations of antibiotics can exert selective pressure sufficient to drive resistance in bacterial populations [81]. A landmark finding in 2001 was the isolation of



an antibiotic-resistant *Salmonella* strain from ground meat, demonstrating that resistant pathogens can be transmitted to humans through contaminated animal products. Subsequent studies confirmed that resistant strains such as *Salmonella* spp., *Campylobacter* spp., and methicillin-resistant *Staphylococcus aureus* (MRSA) can enter the human body via food [35].

AMR is defined as the ability of microorganisms – including bacteria – to survive and proliferate in the presence of agents that previously inhibited or killed them [82,83]. The primary driver of AMR is inappropriate and excessive antimicrobial use. Resistance determinants are transmitted to pathogenic and commensal species through spontaneous mutation and via horizontal (conjugation, transformation, transduction) or vertical gene transfer [84,85,86]. Transmission to humans may occur through ingestion of contaminated food, direct contact with animals, or environmental exposure [87]. Resistance genes can persist in environmental reservoirs even after selective pressure is removed [88].

We are thus entering an era in which many once-effective antibiotics have lost therapeutic utility [89]. According to the ECDC, food-producing animals are reservoirs for AMR pathogens such as *Salmonella* and *Campylobacter*, both primarily transmitted to humans via ingestion [90].

The WHO has designated a group of multidrug-resistant pathogens – the ESKAPE organisms (*Enterococcus faecium*, *Staphylococcus aureus*, *Klebsiella pneumoniae*, *Acinetobacter baumannii*, *Pseudomonas aeruginosa*, and *Enterobacter* spp.) – as high-priority threats because they “escape” standard antimicrobial treatments [91,92]. Consequently, routine hospital procedures now carry a heightened risk of infection with organisms that are increasingly refractory to treatment [93].

A 2022 global systematic analysis of AMR further highlighted the clinical burden of this crisis: in high-income countries, *Staphylococcus aureus* and *Escherichia coli* accounted for nearly half of all AMR-associated deaths, underscoring the urgent need for coordinated international strategies [94].

Toxicity

Although antibiotic toxicology is well characterized in therapeutic contexts, accumulating evidence indicates that chronic dietary exposure to low-level residues can also produce adverse effects. Such residues, present in animal-derived foods, may exert biological impacts that are modulated – amplified or attenuated – by the gut microbiota.

Acute toxicity is rare and usually occurs only when MRLs are exceeded, or banned substances are present. Nevertheless, scientists are increasingly concerned about long-term, low-dose exposure. Subtherapeutic antimicrobial levels ingested chronically have been

linked to alterations in gut microbiota composition, immune dysregulation, and heightened susceptibility to infections, allergic responses, and chronic inflammatory conditions.

Chronic exposure can compromise intestinal homeostasis and weaken systemic immunity, predisposing individuals to both gastrointestinal and extra-intestinal diseases [95]. Emerging data also suggest that even residues below MRLs may affect hepatic metabolism, disrupt endocrine function, and foster the selection of intermediate-resistant bacterial strains.

Allergic reactions

Residues of certain antibiotics have been associated with hypersensitivity reactions. β -Lactam antibiotics are among the most allergenic, and even trace exposure via food can elicit cutaneous manifestations such as maculopapular rashes, erythema multiforme, or exfoliative dermatitis. Severe systemic reactions, including anaphylaxis, can occur even when exposure is limited to sub-MRL concentrations [1,96].

Tetracyclines are also reported to cause dermatologic reactions and phototoxicity, particularly in children [30]. Cephalosporin residues – structurally related to penicillins – may provoke a wide range of adverse effects, from mild eruptions and desquamation to severe conditions such as thrombocytopenia, toxic epidermal necrolysis, and Stevens-Johnson syndrome [8].

Carcinogenic effects

Chronic dietary exposure to antibiotic residues can disrupt intestinal microbiota homeostasis. Such dysbiosis permits the overgrowth of opportunistic pathogens, potentially leading to severe gastrointestinal conditions – including pseudomembranous colitis – and, in the long term, colorectal carcinogenesis [97].

Chloramphenicol is considered hematotoxic and has been associated with irreversible aplastic anemia. However, according to the EFSA, it is not classified as a carcinogen. In the EU, chloramphenicol is banned for use in food-producing animals, with no established MRL, and the primary risk is related to occupational exposure rather than dietary intake. Other antimicrobials – such as sulfamethazine, oxytetracycline, and furazolidone – have demonstrated carcinogenic potential and immunopathological effects in experimental models [30,34].

A study by Hou et al. [98] highlighted the toxicological impact of several commonly detected antibiotic residues – specifically quinolones, tetracyclines, macrolides, β -lactams, and sulfonamides – on male reproductive health. Chronic ingestion of these residues was associated with impaired spermato-



genesis, reduced sperm motility and concentration, decreased testicular weight, histological damage, and an elevated risk of testicular neoplasia. These findings underscore the systemic implications of long-term, low-dose exposure to antibiotic residues in the food chain.

Legal aspects, monitoring and prevention

In the post-war period, when food scarcity was a significant concern, a serendipitous discovery occurred in the late 1940s and early 1950s. The addition of streptogramin to chicken feed markedly enhanced growth rates. Shortly afterwards, in 1949, a similar effect was observed in poultry fed by a post-fermentation product containing trace amounts of chlortetracycline produced by *Streptomyces aureofaciens* [99]. Subsequent studies confirmed that antibiotics also stimulated weight gain in pigs and cattle [100]. Initially, all antibiotics were approved for usage, even though some failed to improve growth, and many were prohibitively expensive. In the late 1960s, the first public debate on using antibiotics solely as growth promoters culminated in the UK “Swann Report” [101]. As interest in the topic grew, more studies documented the adverse consequences of antibiotic use in livestock production, leading to increasingly strict and regulated authorisation regimes [101,102].

Regulations in the EU

The EU began regulating antibiotic use in veterinary medicine with Council Regulation 2377/90, which was subsequently amended and updated, culminating in current Regulations (EU) 2019/6 on veterinary medicinal products and (EU) 2019/4 on medicated feed [103,104]. Because the same classes of chemotherapeutic agents are used in both human and veterinary medicine, posing a public-health risk, Member States must draw up and implement an official feed-control plan each year [105]. The European Parliament and Council established procedures for determining MRLs for pharmacologically active substances in foodstuffs of animal origin under Regulation (EC) No. 470/2009 of 6 May 2009, with specific MRLs provided in Commission Regulation (EC) No. 37/2010 of 22 December 2009 specified the numerical MRLs [106]. Additionally, EU operates the Rapid Alert System for Food and Feed (RASFF), which is designed to enhance official controls in the domain of food safety. The primary objective of the system is to facilitate the rapid exchange of information among competent authorities in EU member states and associated countries. Through RASFF, data concerning food, feed, and food contact materials that may pose risks to human, animal, or environmental health are shared. The system also

outlines specific measures to be implemented when such potentially hazardous products are identified [107].

National regulations in Poland

As an EU Member State, Poland is obliged to implement programs for monitoring antibiotic residues in food. The key instrument is the National Programme for the Control of Certain Substances and Residues of Chemical, Biological and Medicinal Products in Animals and Food of Animal Origin, based on Council Directive 96/23/EC of 29 April 1996 and in force since 2004 [108].

Examples of non-EU countries

According to Nowacka-Kozak et al. [109] every antibiotic authorised for livestock use in the EU has a species- and tissue-specific MRL. South American countries lack comparable regulations, which poses a public health risk if sanitary rules governing imports into the EU are not followed [110]. In Ukraine, similar to the EU, the use of antibiotics for growth promotion in livestock is prohibited [111]. In the US, policy measures have also been progressively tightened. Since January 2017, the use of medically important antimicrobials for growth promotion has been banned, although prophylactic use remains permissible [112]. China, one of the world’s largest consumers of veterinary antibiotics, issued by the Ministry of Agriculture and Rural Affairs a 2019 regulation phasing out medicated feed additives, and updated these guidelines in 2024, banning certain medicated substances altogether [113,114].

CONCLUSIONS

The presence of antibiotics in food is a complex and multifactorial public health issue that originates from practices in animal husbandry, agriculture, and subsequent food processing and packaging. Residues of antimicrobial agents have been detected in meat, milk, eggs, vegetables, and fruits. These residues pose significant health hazards, including the development of AMR, hypersensitivity reactions, toxic effects on internal organs, carcinogenicity, and reproductive dysfunction. AMR, identified by the WHO as one of the most pressing health threats of the twenty-first century, substantially diminishes therapeutic efficacy and contributes to increased mortality and healthcare expenditures.

Although strict regulations exist in the EU and other industrialised regions, gaps in compliance remain, and insufficient surveillance in many developing countries creates worldwide consumer risks.



Final remarks

1. Reducing the use of antibiotics in animal husbandry is imperative and can be achieved through improved hygiene, vaccination, alternative interventions (probiotics) and the development of rapidly biodegradable drugs.
2. Rigorous enforcement of veterinary regulations – including adherence to withdrawal periods and maintenance of treatment records – is essential for minimizing residues in food.
3. Enhanced monitoring of the food supply, especially imports, should involve routine, sensitive testing for pharmaceutical residues.
4. Educating consumers about the hazards of antibiotic residues is crucial for informed dietary choices.
5. Further research is needed to clarify the long-term effects of chronic, low-level antibiotic exposure on gut microbiota, metabolic health, and resistance development.
6. International cooperation, based on the One Health concept, should include data sharing, regulatory harmonisation and joint risk mitigation strategies.
7. Coordinated action at local, national and global levels is indispensable for curbing the spread of antibiotic resistance and safeguarding public health and food security.

Authors' contribution

Study design – J. Kasperczyk

Data collection – K. Lis, G. Myslek

Manuscript preparation – D. Nicz, K. Lis

Literature research – G. Myslek, D. Nicz

Final approval of the version to be published – J. Kasperczyk

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One patient, multiple cardiac implantable devices, a shared threat: T-wave oversensing in the course of hyperkalemia

Jeden pacjent, wiele kardiologicznych urządzeń wszczepialnych,
wspólne zagrożenie: *oversensing* załamka T w przebiegu hiperkaliemii

Michał Krawiec^{1,3} , Aleksandra Hakał¹ , Agnieszka Radziejewicz¹, Oliwia Jewuła¹ ,
Ewa Jędrzejczyk-Patej² , Beata Średniawa³ 

¹Students' Scientific Club, Department of Cardiology and Electrotherapy, Faculty of Medical Sciences in Zabrze,
Medical University of Silesia, Katowice, Poland

²Department of Cardiology and Electrotherapy, Silesian Centre for Heart Diseases in Zabrze, Poland

³Department of Cardiology and Electrotherapy, Faculty of Medical Sciences in Zabrze,
Medical University of Silesia, Katowice, Poland

ABSTRACT

Implantable cardiac devices, such as implantable cardioverter-defibrillators (ICDs) and pacemakers, play a crucial role in the management of patients with severe cardiac arrhythmias. These devices enable continuous monitoring and regulation of cardiac activity, thereby preventing life-threatening arrhythmic events. However, their function may be compromised by electrolyte imbalances, among which hyperkalemia is particularly significant. This condition may result in inappropriate shocks or misdetection of arrhythmias. We present the case of a 42-year-old male with a history of chronic heart failure and end-stage renal disease, who was admitted to a cardiology center for cardiovascular assessment and further management. In 2023, the patient underwent implantation of a subcutaneous implantable cardioverter-defibrillator (S-ICD) due to progressive heart failure. During the course of treatment, the patient experienced an inappropriate S-ICD shock triggered by hyperkalemia (serum potassium concentration of 7.21 mmol/L, which led to increased T-wave oversensing and subsequent inappropriate high-energy therapy). Implantable devices are a cornerstone in the treatment of patients with advanced cardiac arrhythmias; however, their effectiveness is highly dependent on the proper monitoring of serum electrolyte levels. Hyperkalemia can interfere with device sensing and therapy delivery, emphasizing the importance of regular electrolyte assessment, particularly potassium, in patients with implanted cardiac devices.

KEYWORDS

cardiac arrhythmias, hyperkalemia, T-wave oversensing, implantable cardioverter-defibrillator, cardiac pacemaker

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Address for correspondence: Michał Krawiec, Katedra i Klinika Kardiologii i Elektroterapii, Śląskie Centrum Chorób Serca, ul. M. Curie-Skłodowskiej 9, 41-800 Zabrze, tel. +48 32 271 34 14, e-mail: michal.krawiec@interia.eu



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STRESZCZENIE

Kardiologiczne urządzenia wszczepialne, takie jak kardiowertery-defibrylatory (*implantable cardioverter-defibrillators* – ICDs) oraz stymulatory serca, pełnią kluczową rolę w leczeniu pacjentów z brady- i tachyarytmiami. Ich działanie może jednak zostać zakłócone zaburzeniami elektrolitowymi, do których należy hiperkaliemia. Taki stan może być przyczyną nieadekwatnych wyładowań lub błędnej detekcji arytmii. W pracy przedstawiono przypadek 42-letniego mężczyzny z przewlekłą niewydolnością serca i schyłkową chorobą nerek w wywiadzie, przyjętego do ośrodka kardiologicznego w celu oceny układu krążenia i dalszego leczenia. Pacjent przeszedł implantację podskórnego kardiowertera-defibrylatora (*subcutaneous implantable cardioverter defibrillator* – S-ICD) z powodu niewydolności serca ze znacznie zredukowaną frakcją wyrzutową lewej komory. Po implantacji pacjent doznał nieadekwatnego wyładowania S-ICD spowodowanego hiperkaliemią (stężenie potasu sięgało 7,21 mmol/L), która doprowadziła do zjawiska *oversensing*, czyli nadczułości załamka T i nieadekwatnej terapii wysokoenergetycznej. Urządzenia wszczepialne to podstawowa metoda elektroterapii pacjentów z niewydolnością serca. Hiperkaliemia może prowadzić do zakłóceń w działaniu tych urządzeń, co podkreśla konieczność regularnej kontroli stężenia elektrolitów, zwłaszcza potasu, u pacjentów z implantowanymi urządzeniami.

SŁOWA KLUCZOWE

zaburzenia rytmu serca, hiperkaliemia, *oversensing* załamka T, kardiowerter-defibrylator, stymulator serca

INTRODUCTION

Heart failure (HF) represents a growing public health issue, with an estimated global prevalence of approximately 37.7 million patients [1,2]. It is associated with high mortality and constitutes a significant burden on healthcare system, being one of the leading causes of hospitalization among adults and the elderly [2]. The incidence of HF increases with population aging, improved prognosis of patients with ischemic heart disease, and greater societal access to effective therapies that prolong patient survival [3]. The etiology of heart failure is diverse and depends, among others, on sex, age, race, comorbidities, and environmental factors. Most cases of HF develop on the basis of coronary artery disease, chronic obstructive pulmonary disease (COPD), arterial hypertension, as well as valvular heart disease and diabetes mellitus [4,5]. The most common cause of HF is coronary artery disease [6].

HF, depending on left ventricular ejection fraction (LVEF), is classified into:

- HF with reduced ejection fraction (HFrEF), where LVEF is less than or equal to 40%
- HF with mid-range ejection fraction (HFmrEF), where LVEF is 41–49%
- HF with preserved ejection fraction (HFpEF), where LVEF is greater than or equal to 50% and symptoms of heart failure persist [6,7].

The main symptoms of HF are fatigue, dyspnea, and signs of fluid overload, including peripheral edema and pulmonary congestion [8]. Pharmacotherapy constitutes the foundation of HF treatment and should be initiated as first-line therapy, in parallel with non-pharmacological interventions. The main goals of such therapeutic management are the reduction of mortality, prevention of hospitalizations due to HF exacerbations, and improvement of clinical status, exercise capacity, and patient quality of life [7]. The

cornerstone pharmacological agents are angiotensin-converting enzyme inhibitors (ACEIs), angiotensin receptor-neprilysin inhibitors (ARNIs), beta-blockers, and mineralocorticoid receptor antagonists (MRAs). Their mechanism of action is based on modulation of the renin–angiotensin–aldosterone system and the sympathetic nervous system, which improves the general condition of patients [9,10,11].

Despite optimal pharmacotherapy, a significant proportion of deaths among patients are due to sudden cardiac death, often caused by arrhythmias such as ventricular tachyarrhythmias, bradycardia, and asystole [7].

Implantable cardioverter-defibrillators (ICDs) are devices designed to detect and treat life-threatening ventricular arrhythmias. Their operation is based on the detection of ventricular tachycardia or ventricular fibrillation and the application of antitachycardia pacing, and if ineffective, the delivery of a shock to terminate the arrhythmia [12]. The transvenous, or conventional, ICD additionally has pacing functions in cases of bradyarrhythmias. Although ICDs prolong survival in HF patients by preventing sudden cardiac death, the intracardiac leads of conventional ICDs carry a risk of complications such as dysfunction or infective endocarditis. A response to these issues is the development of subcutaneous ICD systems (S-ICD), in which the leads are placed extrathoracically, outside the heart chambers. However, these systems have limitations, namely the lack of capability for continuous cardiac pacing in cases of bradycardia [13]. In addition to S-ICD, another innovation in implantable cardiac devices is represented by leadless pacemakers (Medtronic Micra™ TPS or Abbott Aveir), which constitute an effective alternative to conventional transvenous pacemakers in patients with contraindications to such implantation. They can also be used in combination with S-ICD [14].

Despite the dynamic development of various types of electrotherapy, these modalities are not free from



problems and complications. One such complication, already mentioned above, is lead dysfunction. Another involves device sensitivity issues, such as oversensing or undersensing, both of which may result, in extreme cases, in lack of pacing or inappropriate arrhythmia detection. One such phenomenon is T-wave oversensing (TWOS), which may occur in conventional ICDs, S-ICDs, as well as pacemakers. It is characterized by the incorrect recognition of a T-wave as a ventricular depolarization, which may result in inappropriate ICD or S-ICD detection of tachyarrhythmia [15]. This situation can be triggered by various factors, including hyperkalemia or ischemia. In pacemakers, this may lead to pacing inhibition, whereas in ICDs – to inappropriate shocks [16,17]. Hyperkalemia affects up to 8% of hospitalized patients. Among cardiology patients, it most commonly occurs in elderly individuals treated for HF with concomitant renal failure. It is the most frequent electrolyte disturbance leading to dysfunction of implantable cardiac devices [18]. In the electrocardiographic recording, hyperkalemia manifests with tall, peaked T-waves, progressive flattening of P-waves, and widening of QRS complexes. When plasma potassium exceeds 7.0 mmol/L, cardiovascular manifestations such as atrioventricular blocks, asystole, ventricular tachycardia, or atrial fibrillation may occur. Individual patient sensitivity to elevated potassium levels may vary significantly [19].

CASE REPORT

A 36-year-old patient was transferred in May 2018 from a district hospital to a cardiology center due to decompensated heart failure in NYHA class III. The patient reported a progressive decline in exercise tolerance and exertional dyspnea over the preceding month. Medical history included chronic kidney disease requiring dialysis, secondary hyperthyroidism, and gastroesophageal reflux disease. He had not previously been under cardiology care. Echocardiographic examination revealed severe impairment of left ventricular systolic function (LVEF = 23%) without significant valvular defects. Standard heart failure therapy was initiated. Endomyocardial biopsy confirmed chronic active myocarditis. Steroid therapy was commenced, resulting in improvement of contractility and hemodynamic stabilization. Holter ECG monitoring showed no sustained ventricular arrhythmias. Laboratory tests revealed persistently elevated creatinine levels, N-terminal pro-B-type natriuretic peptide (NT-proBNP) concentration above 35,000 pg/mL, and hyperkalemia (5.47–7.03 mmol/L). The estimated glomerular filtration rate (GFR) was approximately 7 mL/min/1.73 m².

Following clinical stabilization, the patient was discharged with a recommendation for rehospitalization in September 2018 for assessment of ICD implantation indications. Follow-up examinations demonstrated improvement of LVEF to 37%, absence of significant valvular pathology, and nocturnal sinus bradycardia episodes. No sustained ventricular arrhythmias were recorded. Due to improvement in left ventricular function, ICD implantation was not pursued.

In September 2023, the patient presented to the clinic for cardiovascular assessment and potential elective implantation of a subcutaneous implantable cardioverter-defibrillator (Boston Emblem MRI S-ICD). Left ventricular ejection fraction was 22%. The device, with an electrode positioned along the left sternal border, was implanted using the three-incision technique. The procedure was performed under general anesthesia without complications. Subsequent Holter ECG revealed 232 episodes of sinus bradycardia, with a minimum heart rate of 37 beats per minute. Given the history of syncope and bradycardia episodes, the patient was qualified for leadless pacemaker implantation. In January 2024, a 42-year-old man with chronic heart failure, left ventricular dilatation, and end-stage renal disease was admitted for leadless pacemaker implantation due to numerous bradycardia episodes. The procedure and hospitalization were uneventful, and device parameters were within normal limits. S-ICD function was also assessed as normal. The patient was discharged in good general condition.

In March 2024, the patient was electively admitted to the cardiology department for heart transplantation qualification. Echocardiography demonstrated LVEF of 25%, with no valvular defects. Oxygen consumption during cardiopulmonary exercise testing was 15.4 mL/kg/min, and the six-minute walk distance was 418 m. Considering the patient's overall condition, further qualification testing was discontinued.

In June 2024, the patient was urgently admitted following teletransmission confirming an S-ICD shock. Laboratory tests revealed hyperkalemia (7.21 mmol/L). Medical history confirmed that the patient had discontinued sodium polystyrene sulfonate (used to prevent hyperkalemia) several days earlier. ECG demonstrated tall, peaked T-waves. Echocardiographic examination showed no new abnormalities. Hemofiltration was initiated. Leadless pacemaker interrogation revealed no significant abnormalities or arrhythmias. S-ICD interrogation confirmed TWOS and inappropriate detection of ventricular tachycardia, which triggered a high-energy shock. After correction of electrolyte disturbances, no recurrence of TWOS was observed. Following stabilization of electrolyte



abnormalities, the patient was discharged. During one-year follow-up, TWOS did not recur, and the function of both devices remained normal.

DISCUSSION

Over the past decades, significant technological development has occurred in the field of implantable devices. An alternative to conventional transvenous systems has become the S-ICD, which does not require the insertion of electrodes into the heart chambers [20]. The S-ICD represents a particularly beneficial solution in younger patients, in whom the preservation of the venous system is important, as well as in patients with difficult vascular access or a high risk of infections associated with transvenous leads [20,21]. Modern ICDs are equipped with advanced arrhythmia detection algorithms that enable differentiation between supraventricular and ventricular rhythms. This significantly reduces the risk of inappropriate interventions [22].

Despite numerous advantages, implantable cardiac devices are not free from limitations and complications. One example of their malfunction is the possibility of inappropriate shock delivery associated with misinterpretation of T waves (TWOS), which may be caused by factors such as hyperkalemia or repolarization changes [23,24,25]. TWOS is a serious and potentially dangerous phenomenon occurring in patients with implantable cardiac devices [26]. The mechanism of TWOS consists of the device erroneously recognizing a physiological T wave as an independent ventricular impulse, which results in an overestimation of the detected heart rate and may lead to an incorrect diagnosis of ventricular arrhythmia [27,28]. Risk factors for TWOS include young patient age, high left ventricular ejection fraction, low QRS amplitude in lead I of the ECG, repolarization variability (e.g., due to hyperkalemia, physical exertion, or alcohol consumption), and

diseases such as Brugada syndrome [29,30,31]. Cases have also been reported in which TWOS appeared only years after ICD implantation [30]. TWOS is one of the main causes of inappropriate ICD interventions, especially in subcutaneous systems (S-ICD) [32,33]. Management of TWOS is primarily based on adjustment of device settings. This may include changes in detection sensitivity, modification of device parameters, and ICD software updates to improve R- and T-wave discrimination [28,34]. In cases resistant to software modification, generator replacement may be considered. An important role is also played by the identification and correction of secondary causes, such as electrolyte disturbances, in particular hyperkalemia, which significantly alters T-wave morphology and may exacerbate oversensing [16,28,35].

In the literature, cases of TWOS in S-ICD have been reported for various reasons, including one similar to that described herein, namely in a female patient with chronic heart failure and end-stage renal disease, in whom hyperkalemia was the main factor triggering TWOS. Consequently, this led to inappropriate recognition of ventricular rhythm by the device and the delivery of high-energy therapy. In this case, the patient experienced symptoms of general clinical deterioration. As in the present case, the key element of treatment was the correction of electrolyte disturbances. However, additional reprogramming of the ICD was required [25].

CONCLUSIONS

1. TWOS, causing inappropriate S-ICD discharges, is a clinical problem that requires immediate medical intervention.
2. Hyperkalemia may be a cause of inappropriate discharges of implantable cardiac devices.
3. Correction of electrolyte disturbances allows for the limitation of TWOS episodes in S-ICD.

Authors' contribution

Study design – M. Krawiec, A. Hakalo, A. Radziewicz, E. Jędrzejczyk-Patej

Data collection – M. Krawiec, A. Hakalo, A. Radziewicz, E. Jędrzejczyk-Patej, B. Średniawa

Manuscript preparation – M. Krawiec, A. Hakalo, A. Radziewicz, O. Jewuła

Literature research – A. Radziewicz, O. Jewuła, E. Jędrzejczyk-Patej, B. Średniawa

Final approval of the version to be published – M. Krawiec, A. Hakalo, A. Radziewicz, O. Jewuła, E. Jędrzejczyk-Patej, B. Średniawa



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