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Applications of artificial intelligence in medicine: a state-of-the-art review and future perspectives

Zastosowanie sztucznej inteligencji w medycynie: przegląd stanu wiedzy i perspektywy rozwoju

ABSTRACT

This narrative review synthesises peer-reviewed evidence on artificial intelligence (AI) in medicine. We outline technical advances – most notably, large multimodal ("foundation") models – and map validated applications across time-critical detection, ambulatory and bedside monitoring, surgical and imaging augmentation, and drug discovery. Using a lifecycle lens, we highlight dependencies on data governance, external validation, workflow integration and post-deployment monitoring. The analysis shows meaningful gains in earlier detection, efficiency and support for personalised care, alongside heterogeneity in study quality and persistent concerns about bias, equity and privacy.

Keywords: artificial intelligence; foundation models; clinical validation; personalised medicine.

STRESZCZENIE

Niniejszy przegląd narracyjny syntetyzuje recenzowane dowody dotyczące sztucznej inteligencji w medycynie. Przedstawiamy postępy techniczne – zwłaszcza duże modele multimodalne – oraz zweryfikowane zastosowania w detekcji stanów nagłych, monitorowaniu ambulatoryjnym i przyłóżkowym, augmentacji chirurgii i obrazowania oraz w odkrywaniu leków. W ujęciu cyklu życia akcentujemy ład danych, walidację zewnętrzną, integrację z workflow i monitoring po wdrożeniu. Analiza wskazuje na wcześniejsze rozpoznanie, wzrost efektywności i wsparcie personalizacji, przy zróżnicowanej jakości badań i utrzymujących się wyzwaniach równości, uprzedzeń i prywatności.

Słowa kluczowe: sztuczna inteligencja, modele fundacyjne; walidacja kliniczna, medycyna spersonalizowana.

INTRODUCTION. WHAT IS ARTIFICIAL INTELLIGENCE?

Until recently, artificial intelligence (AI) was primarily associated with science fiction; today, it is a reality reshaping everyday life. AI is progressively permeating our activities, playing an increasingly significant role in business transformation, medicine and day-to-day interactions. In doing so, it sets new standards and opens seemingly boundless possibilities.

However, what is AI? For many, artificial intelligence means different things. For some, it is a new mobile application capable of offering personalised suggestions or analysing user habits. For others, it is a robot that can converse with humans and perform tasks ranging from cleaning to cooking. For yet others, AI enables complex scientific endeavours. Multiple definitions circulate because AI is a rapidly evolving field of science; what seemed implausible only a few years ago is now part of routine reality.

Foundational ideas and definitions date back to the mid-twentieth century. In 1955, John McCarthy and colleagues proposed a focused research agenda, defining AI as the construction of machines whose behaviour would be deemed intelligent if exhibited by humans (McCarthy, Minsky, Rochester, & Shannon, 1955). Earlier, Alan Turing had laid theoretical foundations for machine intelligence and articulated criteria for judging intelligent behaviour (Turing, 1950). The field experienced alternating cycles of optimism and retrenchment – from a "golden age" (approximately 1956–1973), through the first "AI winter" (1973–1980), to renewed momentum in the 1980s and subsequent post-millennial developments (2000–2012) – with the present era variously described as an AI transformation or a quiet explosion (Gumkowska & Kondracki, 2022).

AI is an umbrella term encompassing multiple sub-fields that collectively constitute the foundations of this dynamic research area. Data science employs statistical methods, algo-

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rithms and processes to extract insights from large volumes of structured and unstructured data. Optical character recognition (OCR) enables the extraction of text from images, printed materials and handwritten documents, supporting digitisation and large-scale search. Computer vision focuses on the analysis of digital images, including object detection, image classification and 3D modelling; in medicine and autonomous vehicles, vision systems support image-based diagnosis and safe navigation. Automatic speech recognition converts spoken language into text and underpins voice assistants (e.g., Siri, Alexa) and smart-home interfaces. Robotics integrates mechanical, electronic and software systems capable of performing complex tasks; beyond industrial automation and domestic assistance, surgical robotics increasingly augments clinicians in the operating theatre (Gumkowska & Kondracki, 2022).

Across sectors, the application landscape is rapidly expanding. In law, AI is transforming practice by streamlining document analysis and enhancing client-facing services; for instance, Polish LegalTech solutions such as InteliLex offer drafting assistance in Microsoft Word, while DoNotPay has evolved from contesting parking fines to broader document generation and negotiation services (Gumkowska & Kondracki, 2022). For career guidance, Jobbli targets users aged 18–25 with AI-driven profiling that generates detailed reports and recommendations across nearly 300 future-oriented occupations (MamStartup, 2023). In e-commerce, brands utilise AI for recommendation systems and to automate aspects of design and merchandising. Consumer tools, such as SantaGPT, utilise AI to elicit preferences and generate personalised gift suggestions (AI o AI, 2023). Finally, digital advertising leverages generative models—such as generative adversarial networks (GANs) and large language models (LLMs)—and creative tools (e.g., Midjourney), while platforms like AdCreative.ai automate elements of ad content creation (Gumkowska & Kondracki, 2022).

Towards medicine. The remainder of this article turns to AI in healthcare. Building on the technical foundations outlined above, we examine peer-reviewed evidence from the past five years on AI's role across diagnostics, medical imaging, treatment planning, drug discovery, personalised medicine and patient monitoring, with an international perspective and selected contributions from Poland.

1. HISTORICAL BACKGROUND

The intellectual roots of artificial intelligence (AI) lie in mid-twentieth-century computer science and the philosophy of mind, with Turing proposing an operational test for machine intelligence and a programme for learning machines (Turing, 1950). The Dartmouth proposal subsequently articulated a formal research agenda that popularised the term "artificial intelligence" (McCarthy, Minsky, Rochester, & Shannon, 1955). Scholarly syntheses trace alternating waves of optimism and retrenchment – from symbolic reasoning and heuristic search in the 1960s–1970s and the ensuing "AI winter," through the expert-systems revival of the 1980s, to the data-driven machine-learning turn of the 1990s–2000s and the rise of deep representation learning (Haenlein & Kaplan, 2019).

AI's integration into healthcare accelerated with the digitisation of clinical data (electronic health records), advances in medical imaging and the proliferation of biosensors. Reviews since 2020 document applications in clinical decision support, image interpretation and workflow automation, alongside maturing evaluation practices (Aung, Wong, & Ting, 2021; Rajpurkar, Chen, Banerjee, & Topol, 2022; Liu et al., 2020). Bibliometric analyses map three decades of growth and shifting topics across health-AI literature (Zhang, Wang, & Li, 2024).

In pharmaceutical R&D, AI has progressed from exploratory pilots to mainstream components of discovery pipelines. Foundational reviews describe machine-learning contributions to target identification, virtual screening and de novo molecular design, while emphasising the importance of data quality and realistic claims about translational impact (Vamathevan et al., 2019; Jiménez-Luna, Grisoni, & Schneider, 2021; Bender & Cortés-Ciriano, 2021).

Since 2020, the field has increasingly adopted multimodal and foundation-model approaches that combine images, text, time-series and genomics to support personalised risk prediction and therapy selection (Acosta, Falcone, Rajpurkar, & Topol, 2022; Johnson et al., 2020). In parallel, telemedicine and remote monitoring have expanded, with umbrella and scoping reviews highlighting gains in access and outcomes but also heterogeneity of evidence (do Nascimento et al., 2023; Kuan, Ho, Shih, & Chen, 2022; Sharma, Bashir, & Lu, 2023). Ethical and legal analyses foreground data protection, bias and accountability, underscoring the need for robust oversight in clinical deployment (Naik et al., 2022).

2. AI IN MEDICINE – A PANORAMA OF APPLICATIONS

Medicine arguably represents the most consequential domain for artificial intelligence (AI). Within a philosophy of technology lens, AI is becoming an architect of the future of health; yet, its advances must be balanced by governance that mitigates unforeseen harms. Today, AI permeates clinical pathways from diagnosis and treatment to data governance, enabling earlier disease detection, precision therapeutics and more efficient use of scarce clinical resources.

Figure 1 summarises the end-to-end lifecycle of medical AI – from data acquisition and governance through model development and clinical evaluation to deployment and post-deployment monitoring – emphasizing transparency, bias control and continuous human oversight.

In practice, medical-AI solutions are highly heterogeneous, ranging from time-critical detection and triage, through ambulatory and bedside monitoring, to surgical and imaging augmentation, and further to discovery pipelines and emerging generalist multimodal models. We analyse several representative cases – not as an exhaustive catalogue, but to illustrate the breadth of use – prioritizing peer-reviewed evaluations and real-

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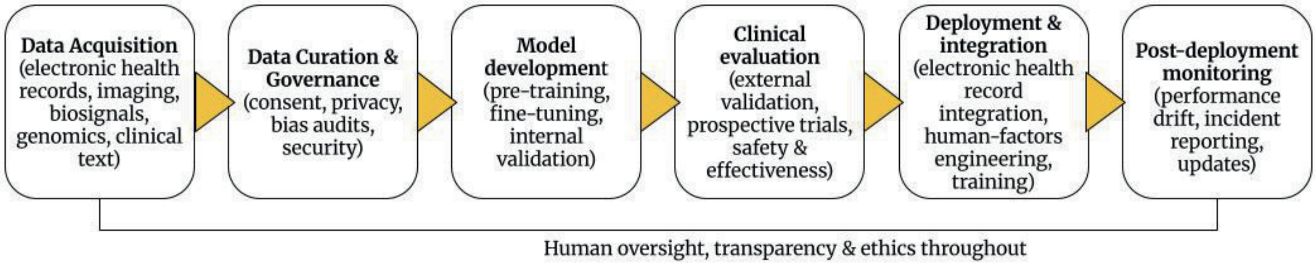

Figure 1. AI in medicine: From data to decisions.
Source: Authors' own elaboration.

world deployments. Across examples, the emphasis is on validation design, workflow integration and governance for safety, equity and trust.

Detecting time-critical conditions. Sepsis recognition illustrates how deployed machine-learning systems can change care. In a prospective, multi-site study of the Targeted Real-time Early Warning System (TREWS) across five hospitals, timely clinician engagement with alerts was associated with an 18.7% relative reduction in in-hospital mortality and earlier antibiotic administration (Adams et al., 2022). Adoption dynamics and workflow context are pivotal for impact (Henry et al., 2022).

Cardiac monitoring outside the hospital. Handheld six-lead mobile ECGs (e.g., clinical class devices comparable to KardiaMobile 6L) have been validated against 12-lead ECGs for rhythm analysis and QTc assessment. Prospective trials report good agreement for diagnostics and safe ambulatory QTc monitoring, supporting use in triage and follow-up (Azram et al., 2021; Bergeman et al., 2023).

Neurology and wearables. For epilepsy, multimodal wrist-worn systems that combine accelerometry with electrodermal activity have undergone prospective validation in epilepsy monitoring units, achieving clinically useful performance for detecting convulsive seizures and notifying caregivers (Onorati et al., 2021). Beyond detection, machine-learning models are being studied for predicting surgery outcomes and therapy response, signalling a broader role in decision support (Sheikh et al., 2024).

Stroke imaging and triage. Deep-learning tools can flag large-vessel occlusion (LVO) on CT angiography within minutes, accelerating specialist notification. Multi-centre and real-world studies show improvements in radiology turnaround and transfer metrics, with mixed but evolving evidence for patient-level outcomes (Soun et al., 2023; Brugnara et al., 2023; Kim et al., 2024).

Surgery augmented by AI. Contemporary robotic platforms increasingly integrate AI-enabled computer vision for instrument tracking, workflow recognition and decision support. Reviews highlight maturing evidence for safety/efficiency gains and outline regulatory and integration hurdles (Szollosi & Iftikhar, 2024). Parallel work from Japan documents the social implementation of telesurgery infrastructure, underscoring technical feasibility and clinical governance requirements for remote operations (Kakeji et al., 2022). Computer-vision research now maps surgical phases, predicts remaining time, and analyses team non-technical skills from OR video, pointing to practical pathways for skills training and quality improvement (Mascagni et al., 2022; Harari et al., 2024).

Caveats from patient-facing tools. Autonomous kiosks and AI-based symptom checkers promise access at scale, but systematic reviews consistently report low diagnostic accuracy and variable triage performance, reinforcing the need for careful oversight and post-deployment monitoring (Wallace et al., 2022; Riboli-Sasco et al., 2023; Hammoud et al., 2024).

Poland in context. Polish teams are actively prototyping AI-enabled dashboards, remote-monitoring and imaging tools. While many solutions are emerging from industry–academia collaborations, rigorous peer-reviewed evaluations remain the bottleneck; accordingly, the academic citations below emphasise international evidence streams that set methodological benchmarks.

3. THE FUTURE OF AI

Following a decade of rapid progress, today's innovations are best read as a preview of broader transformation ahead: in health care, artificial intelligence (AI) is expected to augment rather than replace human labour, shifting routine, high-volume tasks to machines and reserving clinicians' time for empathy, complex reasoning and coordination – provided that human-AI teaming and governance are designed well (Moor et al., 2023; Thirunavukarasu et al., 2023).

In drug discovery and development, AI is poised to penetrate each stage – from target identification and virtual screening to de novo molecular design – while landmark resources such as AlphaFold's structural predictions (>200 million proteins) expand hypothesis space; nonetheless, AI will not obviate clinical trials, and translation will depend on rigorous validation and attention to data quality and bias amid still-substantial costs and timelines (Jumper et al., 2021; Varadi et al., 2022; Wouters et al., 2020).

In clinical workflows, generalist and multimodal foundation models suggest unified interfaces across imaging, text, time-series and genomics, with early opportunities in documentation, decision support and education, but with parallel risks around factuality, bias and over-reliance; likewise, patient-facing chatbots show promise for behaviour change and self-management, yet require careful evaluation and post-deployment monitoring (Moor et al., 2023; Thirunavukarasu et al., 2023;

Aggarwal et al., 2023; Laymouna et al., 2024).

In silico medicine will likely advance through digital twins, where mechanistic organ models are fused with real-world data to support diagnosis, risk stratification and therapy selection, simultaneously raising questions of validation, accountability and equity (Corral-Acero et al., 2020; Nagaraj et al., 2023; Zhang et al., 2024).

In continuous monitoring, wearable sensing and photoplethysmography (PPG) aim to deliver cuffless blood pressure estimation. Evidence to 2024 demonstrates feasibility, but heterogeneous accuracy across devices and populations, and robust calibration/validation standards remain a prerequisite for large-scale clinical adoption (Islam et al., 2022; van Vliet et al., 2024).

In evidence-based digital therapeutics (DTx), software interventions are gaining regulatory traction and health-economic support – e.g., UK recommendations for digital CBT for insomnia – while systematic mappings show a rapidly growing trial pipeline with indication-specific effectiveness dependent on engagement and service integration (Wise, 2022; Sampson et al., 2022; Wang et al., 2023; Miao et al., 2024).

In decentralised diagnostics, home sampling and robotic venepuncture point to more accessible pathways for testing, with early studies reporting acceptable safety and user experience, though robust comparative trials and pathway design are still needed before routine deployment (Leipheimer et al., 2020; Dasari et al., 2024).

Beyond technical trajectories, the philosophical horizon centres on identity, agency and responsibility in medicine: the aim is not to surrender judgement to algorithms but to amplify human care through transparent, accountable systems that earn trust and demonstrably improve outcomes; under these conditions, AI is likely to expand access and quality while keeping clinicians at the heart of compassionate practice (Moor et al., 2023; Thirunavukarasu et al., 2023).

CONCLUSIONS

Current deployments of AI reflect long-standing aspirations about augmenting human capability, yet they also surface enduring philosophical questions about identity, agency and responsibility. As systems learn, analyse data, and even assist in diagnosis, we must clarify the boundaries of human judgement and machine support. Rather than a quest to supersede clinicians, the credible path is to design AI that amplifies human care, is transparent, accountable, and evaluated for real-world benefits. Many ethical dilemmas remain unresolved, but evidence to date suggests AI can improve quality of life and open new horizons in medicine, science and the broader economy when embedded within robust governance. The future, therefore, lies in disciplined optimism: advancing technical innovation while investing equally in validation, equity, privacy and public trust.

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