Innovation, Biomedicine, and Ethical Responsibility

ARTIFICIAL INTELLIGENCE IN BIOMEDICINE: CURRENT APPLICATIONS AND ETHICAL IMPLICATIONS

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ABSTRACT

The integration of artificial intelligence (AI) into biomedical research and clinical practice has expanded rapidly over the past decade, profoundly influencing diagnostic strategies, therapeutic development, and the organization of healthcare systems. Current narrow AI approaches, including deep learning architectures and large language models (LLMs), have demonstrated substantial utility in the analysis of large-scale biomedical datasets, automated interpretation of medical images, synthesis of scientific literature, and prediction of clinical outcomes. These technologies have contributed to improved efficiency, enhanced decision support, and accelerated translational research.
Beyond these established applications, artificial general intelligence (AGI) has emerged as a conceptual and technological frontier, attracting growing scientific interest due to its theoretical capacity to perform complex cognitive tasks autonomously across multiple domains. Unlike task-specific AI systems, AGI is envisioned as capable of integrating heterogeneous information, transferring knowledge between contexts, and adapting dynamically to novel problems. Such capabilities raise fundamental questions regarding the

reliability, transparency, interpretability, and accountability of AI-driven decision-making in sensitive biomedical and clinical environments.
This review provides a comprehensive and up-to-date overview of contemporary AI technologies applied to biomedicine, with particular emphasis on their methodological foundations and practical implications. It further examines the conceptual distinctions between narrow AI and AGI, highlighting the potential contributions of advanced AI systems to scientific discovery, personalized medicine, and integrated clinical care. In parallel, the review critically addresses key ethical, regulatory, and societal challenges, including data privacy, algorithmic bias, clinical responsibility, and equitable access to AI-enabled healthcare.
In summary, artificial intelligence constitutes a major driver of innovation in biomedicine, offering unprecedented opportunities to enhance research and patient care. However, its sustainable and ethical integration into healthcare systems requires not only technological advancement but also rigorous evaluation, transparent governance frameworks, and close collaboration among clinicians, researchers, engineers, and policymakers.
Keywords:*Artificial intelligence; Artificial general intelligence; Machine learning; Deep learning; Ethical issues; Translational medicine.*

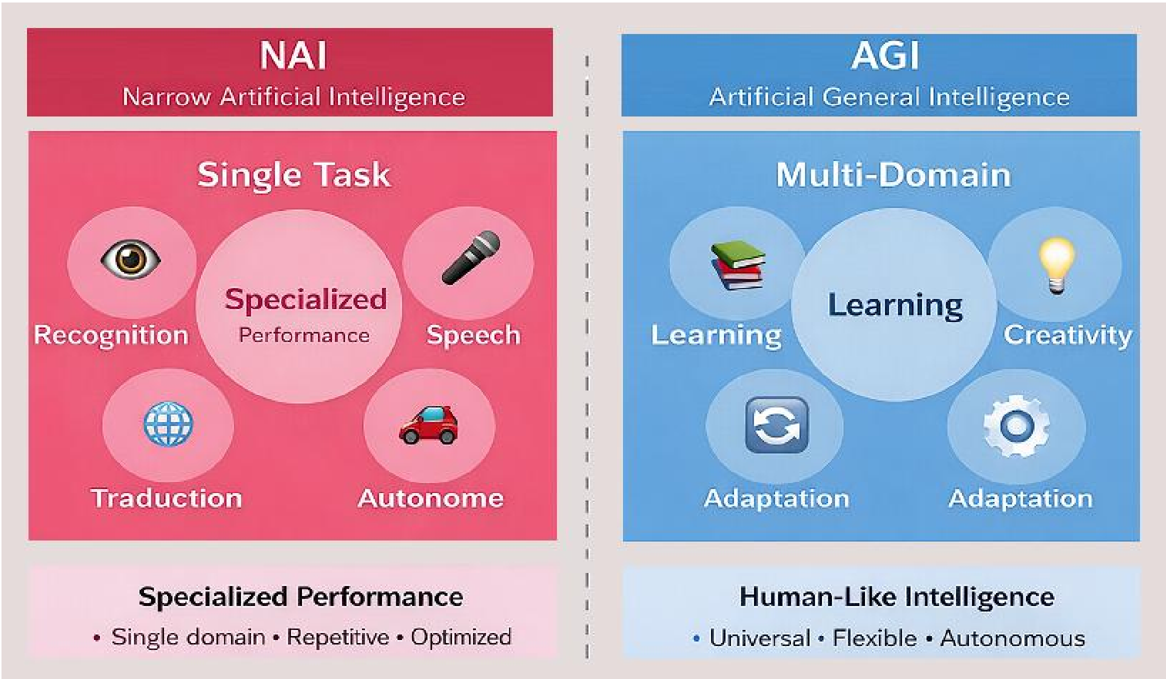
1. CONTEXT: Artificial intelligence today

1.1. Definitions and Terminology

The term *artificial intelligence* (AI) refers to a broad set of computational methodologies that enable machines to perform tasks traditionally associated with human cognitive functions, including learning from experience, pattern recognition, reasoning, and decision-making. Contemporary AI systems are predominantly grounded in machine learning (ML) and deep learning (DL) techniques, which rely on multilayered neural network architectures to extract meaningful representations from large and complex datasets (1,2). These approaches have enabled substantial progress across biomedical research and clinical practice, particularly in domains characterized by high-dimensional data.
From a conceptual standpoint, AI is commonly classified into two major categories based on scope and cognitive capabilities:

a. **Narrow Artificial Intelligence (Narrow AI or NAI):** Systems specifically designed to perform well-defined tasks within restricted domains. In biomedicine, Narrow AI has achieved remarkable performance in applications such as medical image interpretation, signal processing, and biological sequence analysis, while remaining dependent on task-specific training and predefined objectives.
b. **Artificial General Intelligence (AGI):** A largely theoretical construct referring to an AI system capable of understanding, learning, and performing a wide range of complex cognitive tasks at a level comparable to human intelligence. Unlike Narrow AI, AGI is

envisioned to exhibit cross-domain reasoning, contextual understanding, and adaptive learning without being constrained to a single application area (3). Figure 1 illustrates the conceptual distinction between Narrow AI and AGI.



NAI: Narrow Artificial Intelligence; **AGI:** Artificial General Intelligence.

Figure 1. Narrow artificial intelligence (NAI) versus artificial general intelligence (AGI).

2. AI APPLICATIONS IN BIOMEDICINE: Current state

2.1 AI-assisted diagnostics

The application of AI to medical diagnosis represents one of the most extensively studied and documented advances. DL-based models, such as convolutional neural networks, have demonstrated performance superior to or equivalent to that of human experts in identifying radiological abnormalities, skin lesions, and retinal pathologies (4). A recent Wall Street Journal report highlights the use of AI solutions to optimize hospital processes, such as scan review and identification of undetected cases, while cautioning against potential hallucinations and errors when AI lacks adequate clinical supervision (5).

2.2 Synthesis and analysis of scientific literature

Large Language Models (LLMs) are already being employed to synthesize extensive biomedical literature collections, facilitating the extraction of key insights, automated review writing, and interpretation of complex data. A recent bibliometric review demonstrates rapid growth in publications linking AI and biomedicine, particularly for diagnostic, predictive, and knowledge discovery tasks (6).

2.3 Support for translational research

AI platforms combining computer vision, neural networks, and multimodal learning have been developed for practical applications in personalized oncology, where they integrate histological, genomic, and clinical data to propose diagnostic decisions with high accuracy (7).

3. TOWARD ARTIFICIAL GENERAL INTELLIGENCE (AGI)

3.1 Conceptual characteristics of AGI

Unlike current Narrow AI systems, which excel in specific niches, AGI would aim to perform a broad variety of intellectual tasks without dependence on a restricted training dataset or a single application domain (3). Within this framework, AGI would be capable of:

- **Abstract generalization**: understanding underlying conceptual principles and applying them to novel problems without direct supervision (3);
- **Authentic causal reasoning**: moving beyond statistical correlation to infer cause-and-effect relationships;
- **Autonomous learning**: adjusting its internal models without continuous human intervention.

A recent analysis suggests, however, that achieving these capabilities at a truly generalized level remains constrained by biological, infrastructural, and scientific governance limitations, even though substantial acceleration of cognitive tasks is anticipated (8). Table 1 compares the fundamental characteristics of current Narrow AI systems and theoretical AGI, highlighting differences in reasoning, autonomy, and application domain.

Table 1. Comparison between Narrow Artificial Intelligence (Narrow AI) and Artificial General Intelligence (AGI).

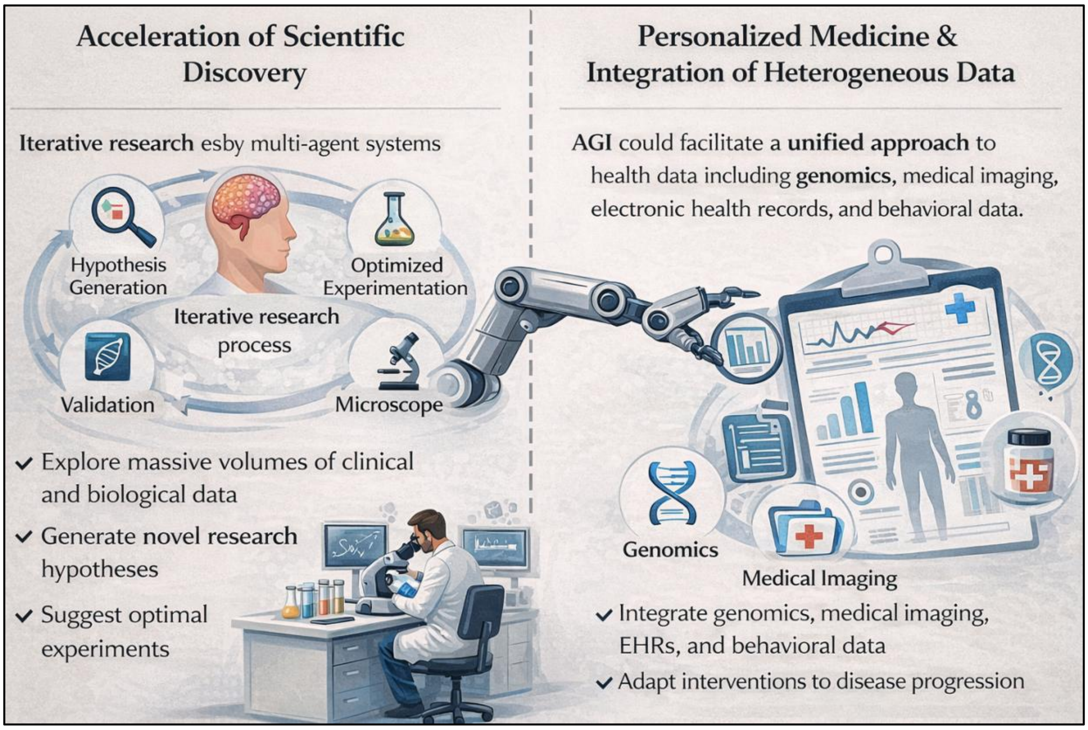
Feature	Narrow AI	Artificial general intelligence (AGI)
Application domain (1,3,4)	Specific and limited	General, multi-domain
Learning (3,8)	Dependent on a specific dataset	Self-directed, continuous learning
Reasoning capability (3,8)	Pattern recognition, statistical correlation	Causal and conceptual reasoning
Autonomy (3,8)	Requires human supervision	Capable of independent goals and dynamic adjustment
Adaptability (3,8)	Limited to known environments	Capable of adapting to new contexts
Typical applications (2,3,7)	Radiological diagnosis, image recognition, LLMs	Hypothesis generation, autonomous experimentation, personalized medicine

LLM (Large Language Model): Trained on massive text corpora; capable of understanding, generating, and summarizing natural language. Examples: ChatGPT – conversational model optimized for interaction and writing assistance; GPT-4 – advanced model with enhanced reasoning.
LLaMA (Large Language Model Meta AI): Family of language models by Meta, designed for research and open science.

4. POTENTIAL APPLICATIONS OF AGI IN HEALTHCARE

Artificial General Intelligence (AGI) represents a theoretical yet potentially transformative paradigm in healthcare, extending beyond task-specific artificial intelligence toward systems capable of autonomous reasoning, knowledge transfer, and adaptive decision-making across domains. Unlike current narrow AI applications, AGI could integrate diverse sources of biomedical knowledge, infer causal relationships, and dynamically refine hypotheses in response to emerging evidence. Such capabilities hold the promise of profoundly reshaping biomedical research, clinical decision-making, and personalized care by enabling large-scale data synthesis, hypothesis-driven experimentation, and continuous learning within complex biological systems.

The following sections highlight two major domains in which AGI could exert a disruptive impact: the acceleration of scientific discovery and the implementation of truly personalized medicine through the integration of heterogeneous health data. Figure 2 schematically illustrates these potential applications of AGI in healthcare, emphasizing its role in hypothesis generation, experimental optimization, and the integration of multimodal clinical and biological data to support adaptive and individualized therapeutic strategies.



AGI: Artificial General Intelligence **; HER:** Electronic Health Records.

Figure 2. AGI-Enabled Pathways for Biomedical Discovery and Precision Medicine.

4.1 Acceleration of scientific discovery

The integration of advanced AI agents could theoretically analyze, in parallel and at scale, massive corpora of clinical and biological data to generate novel research hypotheses, design optimized experiments, and suggest personalized therapeutic interventions. Multi-agent systems already under exploration employ iterative processes of generation, debate, and evolution to propose therapeutically relevant hypotheses validated in laboratory settings (9).

4.2 Personalized medicine and integration of heterogeneous data

AGI has the potential to revolutionize personalized medicine by enabling the comprehensive integration of diverse biomedical datasets. These datasets encompass genomic profiles, high-resolution medical imaging, electronic health records, wearable device outputs, and behavioral or lifestyle information. By synthesizing these heterogeneous sources, AGI could construct dynamic, patient-specific models of disease trajectory, thereby allowing clinicians to anticipate disease progression, stratify risk more accurately, and tailor therapeutic interventions with unprecedented precision (10).

Beyond individualized patient care, the capacity of AGI to process and learn from complex, multidimensional data positions it as a powerful tool for biomedical research. For instance, AGI could identify previously unrecognized patterns across populations, generate hypotheses for mechanistic studies, and optimize clinical trial design by predicting patient responses. Table 2 provides a concise overview of the current landscape of AI applications in biomedicine and highlights the future potential of AGI to execute tasks requiring advanced reasoning, multi-domain knowledge integration, and adaptive learning in scientific and clinical contexts.

Table 2. Recent applications of artificial intelligence (AI) in biomedicine and the potential of artificial general intelligence (AGI).

Application domain	Technology used	Results and benefits	Application domain
Medical diagnosis (4,5)	CNN, deep neural networks	Accurate lesion detection, workflow optimization	Medical Diagnosis
Literature synthesis (2,3,6)	LLMs (ChatGPT, GPT-4, LLaMA)	Rapid summarization of thousands of articles, writing assistance	Literature synthesis
Drug discovery (2,7)	DeepMind AlphaFold, autonomous platforms	Protein structure prediction, experimental optimization	Drug discovery
Personalized medicine (10,12)	Multimodal AI integrating EHR and genomics	Patient-tailored predictive models	Personalized medicine
Hypothèse scientifique autonome(3,8,9)	IAG (hypothetical)	Hypothesis generation, optimized experimentation	Autonomous scientific hypothesis

CNN (Convolutional Neural Network): A deep learning architecture particularly effective for medical image analysis (radiology, histopathology, functional imaging), due to its ability to automatically extract complex spatial features.

LLM (Large Language Model): A large-scale language model trained on massive text corpora, capable of understanding, generating, and summarizing natural language. Examples:

1. **ChatGPT:** A conversational model based on GPT, optimized for interaction and writing assistance.
2. **GPT-4 (Generative Pre-trained Transformer 4):** An advanced text generation model with enhanced reasoning capabilities.

LLaMA (Large Language Model Meta AI): A family of language models developed by Meta, designed for research and open science applications.

DeepMind AlphaFold: A deep learning–based AI system developed by DeepMind, capable of accurately predicting the three-dimensional structure of proteins from their amino acid sequences.

Multimodal AI: An approach combining multiple types of heterogeneous data (text, imaging, clinical, biological, genomic) to enhance predictive performance and medical decision-making.
EHR (Electronic Health Records): Digital patient records aggregating longitudinal clinical data, including medical history, diagnoses, treatments, laboratory results, and imaging.
AGI (Artificial General Intelligence): A theoretical concept of AI capable of understanding, learning, and performing any complex cognitive task at a human level, autonomously and transferable across domains, without being limited to a specific application.

5. ETHICAL, SOCIAL, AND REGULATORY CHALLENGES

5.1 Data privacy and security

The increasing use of artificial intelligence systems in healthcare relies on access to massive volumes of individual data, including clinical, genetic, and behavioral information. This necessity raises major concerns regarding patient privacy, informed consent, and the protection of sensitive data against risks of leakage, hacking, or unauthorized secondary use.

International and national legal frameworks play a central role in regulating medical AI. In Europe, the General Data Protection Regulation (GDPR) imposes strict standards on the collection, processing, storage, and sharing of personal data, particularly when advanced or autonomous AI systems are involved (11). These standards include data anonymization or pseudonymization, patients' rights of access and rectification, and documentation of algorithmic processing.
Beyond legal obligations, technical and organizational data security constitutes an essential pillar. Systems must integrate encryption mechanisms, access controls, traceability, and auditability, ensuring that only authorized personnel can access sensitive information and that each use is traceable and justifiable. Moreover, AI itself can be leveraged to enhance cybersecurity, for example by detecting anomalies or intrusions in medical databases.
Finally, privacy and security challenges are not purely technical or regulatory: they directly impact the trust of patients and healthcare professionals, conditioning the responsible and ethical adoption of AI technologies in medicine. Ensuring the protection of sensitive data is therefore essential to reconcile technological innovation with respect for fundamental rights.

5.2 Bias, equity, and interpretability

Machine learning (ML) and AI models used in healthcare are trained on extensive corpora of clinical, biological, or sociodemographic data. When these datasets reflect historical biases whether related to ethnicity, gender, age, socioeconomic status, or healthcare access models can systematically reproduce and amplify these biases. This phenomenon can lead to inappropriate therapeutic recommendations, biased risk scores, or diagnostic errors, particularly among vulnerable populations already underrepresented in training cohorts (12).

Algorithmic fairness is not merely a question of performance: it requires critical evaluation of input data, differential performance metrics across subgroups, and bias mitigation strategies at each stage of model development. Furthermore, interpretability defined as the capacity to transparently explain a model's decisions or predictions is essential to ensure the trust of clinicians and patients, facilitate system auditability, and enable safe adoption in clinical contexts. Several recent reviews emphasize the necessity of designing algorithms that are not only performant but also interpretable, robust, and equitable, to prevent AI integration from reproducing or exacerbating existing health disparities.

5.3 Accountability and clinical governance

The question of accountability in cases of errors generated by autonomous artificial intelligence systems is particularly complex and multidimensional.

In contexts where advanced AI or AGI directly participates in clinical decision-making, it becomes imperative to establish clear and robust governance frameworks involving algorithm developers, clinicians, healthcare institutions, and regulatory authorities. These frameworks must precisely define who is legally and ethically accountable in cases of adverse events whether an erroneous diagnosis, inappropriate prescription, or treatment error.
Beyond legal aspects, accountability also encompasses system traceability and auditability, ensuring that each decision can be traced and explained, thereby strengthening patient safety and healthcare professionals' trust.
Clinical governance of AI must also integrate mechanisms for continuous evaluation, independent performance review, and proactive risk management, particularly for vulnerable populations or critical clinical situations.
Table 3 identifies and describes the principal ethical, social, and regulatory challenges associated with the use of advanced AI and AGI in biomedicine, emphasizing accountability, transparency, equity, and patient safety. These challenges underscore the necessity of balancing technological innovation with the protection of patients' rights and safety, ensuring that AI integration into clinical practice occurs in an ethical, secure, and responsible manner.

Table 3. Ethical issues and challenges associated with ai and agi in healthcare.

Enjeu	Description	Impact potentiel
Privacy (11)	Access to massive health datasets	Risk of breaching medical confidentiality
Algorithmic bias (12)	Models trained on non-representative data	Disparities in care, diagnostic errors
Clinical liability (11)	Errors generated by autonomous AI	Ambiguity regarding responsibility (developer, physician, institution)
Transparency and Interpretability (12)	Difficulty in understanding AI decisions	Limits trust and clinical adoption
Safety and Control (8)	Possibility of unexpected behavior from autonomous systems	Risk of physical or ethical harm
Equitable access (12)	Uneven deployment across regions or populations	Risk of exacerbating health inequalities

6. CONCLUSION

Artificial intelligence has already become an integral component of contemporary biomedicine, reshaping diagnostic processes, accelerating data-driven discovery, and enhancing translational research across multiple disciplines. Current narrow AI systems, including deep learning and large language models, have demonstrated substantial value in pattern recognition, predictive modeling, and knowledge synthesis, thereby improving clinical workflows and supporting evidence-based decision-making. These advances underscore the capacity of AI to augment human expertise rather than replace it, particularly in complex medical environments.

In contrast, Artificial General Intelligence remains a largely theoretical construct, representing a qualitative shift toward systems capable of autonomous reasoning, cross-domain knowledge transfer, and adaptive learning beyond predefined tasks. Achieving such capabilities would require major conceptual and technological breakthroughs, including advances in causal inference, explainable reasoning, contextual understanding, and long-term autonomy. While the realization of AGI in healthcare is uncertain, its potential implications for scientific discovery, personalized medicine, and clinical decision-making warrant rigorous interdisciplinary investigation.

Equally important are the ethical, regulatory, and societal considerations accompanying the expanding role of AI in health systems. Issues related to data privacy, algorithmic bias, transparency, accountability, and equitable access must be addressed proactively to prevent unintended harms and the amplification of existing health disparities. The development of robust governance frameworks, coupled with continuous evaluation and human oversight, will be essential to ensure that AI-driven innovations align with core medical values and public trust.

Ultimately, the responsible integration of artificial intelligence into biomedicine depends not only on technological progress but also on ethical stewardship, regulatory adaptation, and sustained collaboration between clinicians, researchers, engineers, and policymakers. By fostering a balanced and critical approach, AI has the potential to serve as a powerful catalyst for biomedical innovation while preserving patient safety, equity, and human dignity.

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