Mètode Science Studies Journal
ISSN: 2174-3487
ISSN: 2174-9221
metodessj@uv.es
Universitat de València
España

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Mètode Science Studies Journal, vol. 15, núm. 7, e30448, 2025
Universitat de València
Valencia, España

DOI: https://doi.org/10.7203/metode.15.30448

MONOGRAPH
METODE SCIENCE STUDIES JOURNAL, 15(7). University of Valencia (2025).
eISSN: 2174-9221.
Submitted: 20/02/2025. Approved: 20/05/2025.
https://doi.org/10.7203/metode.15.30448

ARTIFICIAL INTELLIGENCE IN BIOMEDICINE

Applications and challenges

Ignasi Belda

Artificial intelligence (AI) is transforming biomedicine, advancing diagnostics, drug discovery, and personalised medicine. Techniques such as deep learning and robotic surgery are enhancing precision and efficiency, while natural language processing is facilitating the analysis of clinical data. However, challenges such as data quality, algorithmic bias, and clinical integration still require careful attention. It is crucial to balance innovation and regulation, promote interdisciplinary collaboration, and develop transparent and explainable AI systems. The future of AI in biomedicine is promising, but we need an ethical and collective approach to maximise its positive impact on global health.

Keywords: **artificial intelligence**, **biomedicine**, **diagnostics**, **drug discovery**, **personalised medicine**.

Artificial intelligence (AI) has emerged as a transformative tool in multiple fields, and biomedicine is no exception. AI is traditionally divided into five areas (Belda, 2011) that have shaped its development and application in various fields, including biomedicine. These areas are: search, optimisation, machine learning, natural language processing, and artificial life. Each of them plays a key role in solving complex problems and creating intelligent systems.

«AI has emerged as a transformative tool in multiple fields, and biomedicine is no exception»

As in other disciplines, AI in biomedicine is highly dependent on access to high-quality biomedical data. Such data comes from various sources, including genomes, medical images, clinical records, and other types of health-related information. Each data source offers unique opportunities for research and the application of AI techniques, but also presents specific challenges in terms of acquisition, processing, and interpretation. In this text, we will explore the main sources of biomedical data and their relevance in the field of AI.

First of all, genomes are among the richest and most complex sources of data in biomedicine. They contain the complete genetic information of an organism and are key to studying hereditary diseases, identifying mutations, and developing personalised drugs. Another major source of biomedical data is medical imaging, such as X-rays, computed tomography scans, magnetic resonance imaging, and microscopic images, which provide visual information about the structure and function of organs and tissues. Clinical data includes information such as medical histories, laboratory results, prescriptions, and treatment records. Finally, in addition to genomic, imaging, and clinical data, there are other relevant sources of biomedical data for AI, such as sensor data, among others.

HOW TO CITE::
Belda, Ignasi. (2025). Artificial intelligence in biomedicine: Applications and challenges. *Metode Science Studies Journal*, *15*(7), e30448. **https://doi.org/10.7203/metode.15.30448**

APPLICATIONS OF AI IN BIOMEDICINE

Diagnosis and prediction of diseases

Through techniques such as machine learning and natural language processing, AI is improving the accuracy, speed, and efficiency of diagnostic processes, as well as the ability to detect diseases before they manifest clinically. The following section reviews key applications of AI in this field, with a specific emphasis on medical imaging and the prediction of complex diseases.

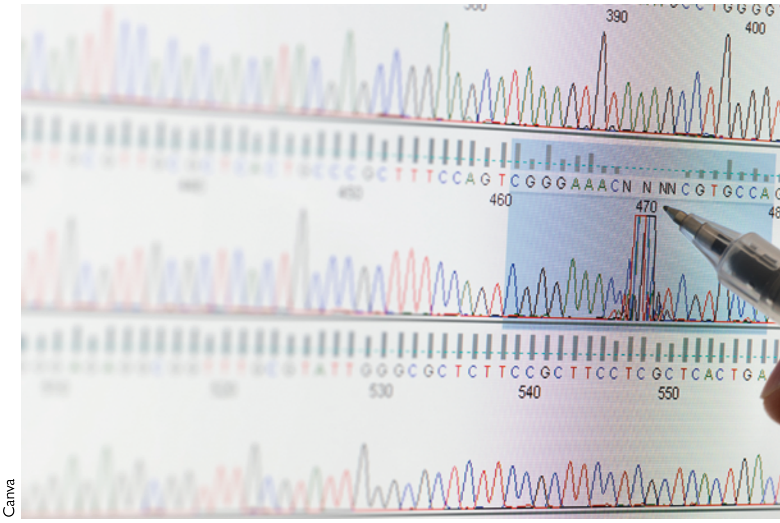
Medical image analysis is one of the areas where AI has had the most significant impact. Deep learning algorithms can process medical images with an accuracy that is comparable to, or even greater than, that of human experts. This is transforming specialties such as radiology, pathology, and dermatology.

For example, in radiology, AI applied to medical image analysis is used to analyse radiographs, computed tomography (CT) scans, magnetic resonance imaging, and other modalities. These techniques enable the detection of abnormalities such as tumours, fractures, or soft tissue injuries (Guardiola et al., 2022). The specialised literature provides numerous examples of deep learning models developed for the early detection of lung cancer in CT scans (Wang, 2022). These algorithms can identify subtle lung nodules that may be overlooked by the human eye, improving early diagnosis rates.

In pathological anatomy, the use of AI-based technologies is also becoming increasingly common. Specifically, these systems are applied to the analysis of microscopic images of tissues and cells (Tosun et al., 2020), which are key for diagnosing diseases such as cancer. AI algorithms can analyse biopsy images to identify cancer cells in tissues. In breast cancer, for instance, AI helps classify tumours according to their type and grade (Sheth & Giger, 2020), which is essential for treatment planning.

Beyond diagnosis through medical imaging, AI is also revolutionising the prediction of complex diseases such as cancer, cardiovascular conditions, and neurodegenerative disorders. These techniques allow the identification of patterns in data that may indicate a high risk of developing a disease before clinical symptoms manifest.

In this sense, numerous studies in the academic literature have demonstrated the potential for AI in detecting cancer using genomic, clinical, and lifestyle data; in predicting cardiovascular events such as heart attacks or strokes; and in identifying early signs of neurodegenerative diseases such as Alzheimer's or Parkinson's (Singh et al., 2025; Xu et al., 2019).



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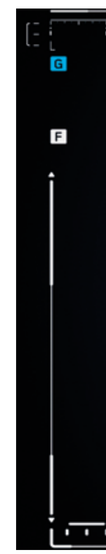

«AI enables the analysis of large volumes of genomic data to identify genetic biomarkers associated with diseases or treatment responses»

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AI is having a significant impact in two key areas: drug design and drug repositioning.

Drug discovery and therapy development

Drug discovery is a complex, expensive, and time-consuming process. Traditionally, it can take more than a decade and involve billions of dollars in investment to bring a new drug to market. AI is now having a major impact in this field, accelerating the discovery process and reducing costs. In particular, AI is transforming two key areas: drug design and drug repositioning. The following sections describe how these applications are transforming the pharmaceutical industry.

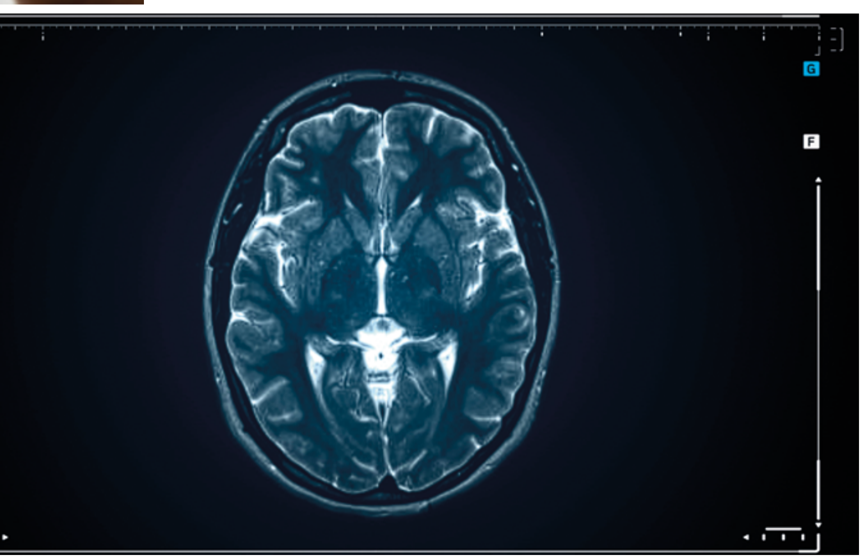
Drug design involves the creation of new chemical compounds that can interact with specific therapeutic targets to treat diseases. AI is optimising this process through the use of techniques such as machine learning and deep learning, which enable the analysis of large volumes of data and the prediction of how different compounds will interact with the human body.

The design of a new drug is a long, costly, and complex process that encompasses several phases. One of these is the prediction of molecular interactions. In this context, AI can predict how a molecule will interact with a protein or other biological target (a therapeutic target), allowing the identification of compounds with therapeutic potential before laboratory testing.

AI can also generate new chemical compounds with desirable properties. This is achieved through techniques such as generative adversarial networks, molecular language models, or evolutionary computing (Belda et al., 2007), which enable the design new molecules by optimising properties such as affinity, specificity, and safety.

Once a promising compound has been identified, AI can help optimise it to improve its efficacy and safety. This includes modifying the chemical structure to improve its binding capacity to the therapeutic target (Belda et al., 2005). Thus, AI algorithms can evaluate thousands of molecular variants and select the most effective ones for subsequent experiments, thereby accelerating optimisation and reducing development costs.

Another strategy for bringing new treatments to market is drug repositioning, a pharmacological approach that seeks new therapeutic applications for existing medicines. This method is particularly attractive because repositioned drugs have already passed the initial safety phases, which reduces development time and cost (Tanoli et al., 2021). AI plays a key role in this field by identifying potential new uses for approved drugs through the analysis of genomic, clinical, and pharmacological data.



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In the field of medical image analysis, AI is used to analyse radiographs, computed tomography scans, and magnetic resonance imaging, etc. These techniques allow the detection of abnormalities such as tumours, fractures, or soft tissue injuries.

«Through techniques such as machine learning and natural language processing, AI is improving the accuracy, speed, and efficiency of diagnostic processes»

Personalised medicine and genomics

Personalised medicine, also known as *precision medicine*, seeks to adapt medical treatments to the individual characteristics of each patient. This approach is based on the analysis of genomic, clinical, and lifestyle data to make more precise and effective decisions. In this field, AI is also playing a key role, especially in the analysis of genomic data and the prediction of drug responses. The following section explores these applications and how they are transforming personalised medicine.

For example, AI enables the analysis of large volumes of genomic data to identify genetic biomarkers associated with diseases or treatment responses. These capabilities are especially valuable in planning cancer treatments, where genomic analysis can identify specific mutations that make a tumour more sensitive to certain drugs. This allows to select more effective treatments and avoid those that are unnecessary or potentially harmful (Singh et al., 2025).

Genomic medicine can also use genome information to prevent, diagnose, and treat diseases. AI facilitates this process through the rapid and accurate analysis of complex genomic data, which is widely applied in the diagnosis of rare diseases. Genomic analysis can identify disease-causing mutations, allowing the development of personalised treatments or the enrolment of patients in targeted clinical trials.

However, one area in which AI is having a significant impact is in next-generation sequencing (NGS), which generates massive amounts of genomic data that are difficult to interpret manually. AI allows the efficient processing and analysis of these datasets (Choon et al., 2024). Indeed, AI models are increasingly used to analyse NGS data to identify genetic variants associated with diseases such as cancer, Alzheimer's, and diabetes.

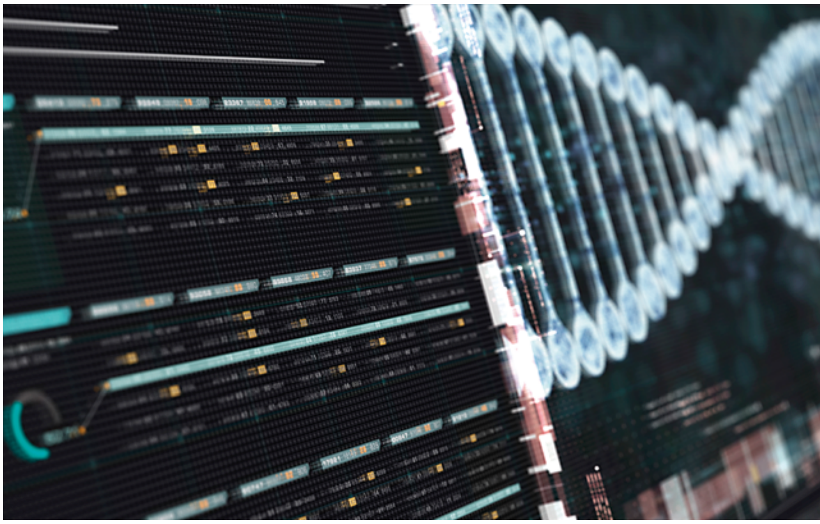
In addition, AI can also be used to predict drug responses, which can vary significantly between patients due to genetic, environmental, and lifestyle factors. AI-based models can predict how an individual will respond to a specific treatment, thereby improving efficacy and reducing adverse effects (Abbas et al., 2024). This branch of pharmacology, known as *pharmacogenomics*, studies how genes affect patient responses to medications. A clear example is in oncology, where AI can predict which drugs will be most effective based on the genetic profile of a tumour. This allows the selection of personalised treatments that maximise efficacy and minimise toxicity.

Finally, AI is also being applied to help determine the optimal drug dosage for each patient, taking into account factors such as age, weight, kidney function, and genetic profile. This functionality is especially valuable in patients receiving chemotherapy, where AI can calculate the most effective dose while minimising side effects.

Clinical data management and decision support systems

Efficient management of clinical data and the implementation of decision support systems are key for improving healthcare and optimising hospital resources. AI is playing a fundamental role in these areas, providing technologies that enable the real-time analysis of large volumes of data, the generation of early alerts, and the optimisation of resource allocation. This section analyses how these applications are transforming clinical and hospital management.

Early warning systems based on AI have been developed to monitor patient data and detect signs of medical complications before they become serious (Shaik et al., 2023). These systems are especially useful in hospital settings, where early detection can save lives and prevent severe outcomes. AI can analyse real-time data such as vital signs, laboratory results, and clinical records to identify patterns



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Another strategy for bringing new treatments to market is what is known as *drug repositioning*. This pharmacological methodology consists of finding new applications for existing medicines.

«AI-based models can predict how an individual will respond to a specific treatment, thereby improving efficacy and reducing adverse effects»

indicating a high risk of complications. This capability is especially useful in intensive care units (ICUs), where AI systems can detect signs of deterioration in patients in critical condition including sepsis or organ failure, allowing the medical staff to promptly intervene.

AI can also analyse historical clinical data to predict which patients have higher risk of hospital readmission after discharge. For instance, algorithms can identify patients with heart failure or chronic respiratory diseases who may need additional interventions to prevent readmission. Similarly, AI-driven systems have also been developed that can generate personalised alerts based on the clinical profile of individual patients, taking into account variables such as age, sex, medical history, and underlying conditions.

Efficient resource management remains a critical challenge in hospitals, where demand can often exceed available capacity. AI contributes to optimising the use of resources by analysing operational data and predicting future needs. In this sense, AI can be employed in real time to improve the allocation of hospital beds and the scheduling of operating theatres (Cahyo & Astuti, 2023); to predict peaks in demand in services such as emergencies, ICUs, or diagnostics; and to optimise healthcare workforce management, ensuring that adequate numbers of doctors, nurses, and support staff are available at all times.

Robotic and robot-assisted surgery

Robotic surgery is one of the most advanced and promising applications of AI in medicine. This technology is transforming surgical practice, offering greater precision, minimally invasive procedures, and improved patient outcomes. The combination of AI and robotics allows surgeons to perform complex operations with an unprecedented level of control and accuracy. The following section explores recent advances in surgical robotics and how AI is expanding the capabilities of robot-assisted surgery.

Robotic surgery uses robotic arms controlled by surgeons to perform procedures with enhanced precision and a lower degree of invasion. These systems combine advanced technologies such as computer vision, machine learning, and augmented reality to provide a superior surgical experience.

The best-known example is the da Vinci Surgical System (D'Ettorre et al., 2021), used in hospitals around the world. This platform allows surgeons

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AI can analyse real-time data to identify patterns that point to a high risk of complications. This is especially useful in intensive care units (ICUs), where AI systems can detect signs of deterioration in patients in critical condition in order to alert doctors so they can rapidly intervene.

to operate through small incisions using robotic instruments that replicate the movements of the surgeon's hands with greater precision and stability. AI is simultaneously increasing the capabilities of robotic surgery systems by offering real-time assistance to surgeons. This assistance includes data analysis, intraoperative guidance, and even the automation of specific tasks. For example, in oncological surgery, AI can help delineate tumour margins in real time, ensuring the complete removal of cancerous tissue. This improves the accuracy of tumour excision and reduces the risk of recurrence.

AI can also automate repetitive or high-precision tasks during surgery, freeing surgeons to focus on the more complex aspects of the procedure. A good example is ophthalmic surgery, where AI-assisted robots can make extremely precise corneal incisions during procedures such as LASIK (Chaitra & Rohit, 2020). These technologies provide greater consistency and precision in critical surgical tasks.

«The combination of AI and robotics allows surgeons to perform complex operations with an unprecedented level of control and accuracy»

FUTURE TRENDS AND OPPORTUNITIES

Explainable AI (XAI) (Miró-Nicolau et al., 2024) is an emerging field that seeks to make the decision-making processes of AI models more transparent and understandable. In biomedicine, this is especially important, because healthcare professionals must understand how and why an algorithm reaches a certain conclusion in order to trust its results and make informed decisions. For example, in AI-assisted diagnosis, it is crucial to know which factors led to identifying a tumour as malignant or benign. XAI techniques, such as feature attribution analysis or heatmap generation in medical imaging, help visualise and interpret model results. This not only improves the acceptance of AI in clinical settings but also facilitates the detection of biases or errors in algorithms.

In parallel, the integration of AI with other emerging technologies, such as the Internet of Things (IoT) and blockchain, is opening new possibilities in biomedicine. The IoT, for example, enables the collection of real-time health data through connected medical devices such as smartwatches or wearable sensors which can be analysed by AI models to monitor patient health or detect anomalies.

As AI becomes more prevalent in biomedicine, the need to develop robust regulatory frameworks and international standards to ensure its safe and ethical use is becoming more evident. This includes establishing clear regulations on data quality, AI model validation, and patient privacy protection. For this reason, regulatory agencies such as the US Food and Drug Administration (FDA), have already begun drafting guidelines for the evaluation and approval of AI systems in clinical settings.

The future of AI in biomedicine

AI is having a transformative impact on biomedicine, revolutionising areas such as diagnostics, drug discovery, personalised medicine, and clinical data management. Techniques such as deep learning, natural language processing, and robotic surgery are

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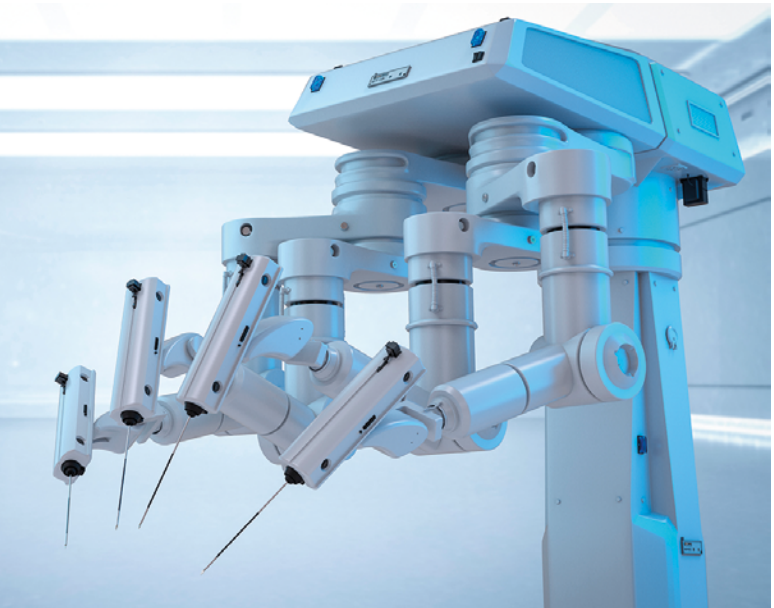

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Robotic surgery systems such as the da Vinci Surgical System are the best-known example and are used in hospitals around the world. These systems allow surgeons to operate using robotic instruments that mimic the movements of a surgeon's hands with greater precision and stability.

improving the accuracy, efficiency, and accessibility of healthcare. These technologies are not only accelerating medical research but also opening new possibilities for prevention, early diagnosis, and the treatment of complex diseases. However, to achieve the full potential of AI, challenges such as data quality, algorithmic biases, and effective integration into clinical practice must be addressed.

To ensure a sustainable future for AI in biomedicine, it is crucial to find a balance between innovation and regulation. On the one hand, we need to promote the adoption of these technologies through interdisciplinary collaboration, the training of healthcare professionals, and the development of regulatory frameworks that ensure their safe and ethical use. On the other hand, it is essential to continue research in areas such as XAI, integration with other emerging technologies, and the improvement of model interpretability. The future prospects for AI in biomedicine are promising, but they require a collective approach that prioritises both technological advancement and patient well-being. ⊙

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