



REVIEW

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# Artificial intelligence in allergy practice: Digital transformation and the future of clinical care

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## ABSTRACT

Bioethics involves the analysis of human behavior in the life and health sciences, grounded in moral values and ethical principles. Its integration into the education and training of healthcare professionals is essential for addressing complex medical dilemmas, while also fostering behaviors that strengthen the doctor-patient relationship. The rapid advancement of technology, particularly artificial intelligence (AI), is transforming medical specialties and reshaping patient care. In the field of allergy and immunology, AI offers promising applications such as enhanced patient education, symptom tracking, personalized treatment planning, and improved clinical decision-making. However, its implementation raises significant ethical concerns. There is a risk of diminishing clinical reasoning skills due to excessive reliance on AI, as well as challenges related to data privacy, informed consent, and algorithmic transparency. These issues pose new bioethical dilemmas regarding patient autonomy and the humanization of care. This review explores the integration of AI in allergy practice, emphasizing its ethical implications and its potential impact on the doctor-patient relationship. Balancing technological innovation with core bioethical principles—non-maleficence, beneficence, autonomy, and justice—is critical for advancing patient-centered care in a digital era.

**Keywords:** Artificial intelligence, Allergy practice, Bioethics

*"Our future is a race between the growing power of technology and the wisdom with which we use it. Let's make sure that wisdom wins."<sup>1</sup>*

This phrase written by Stephen Hawking gives us an idea of the impact that technologies can

have in various aspects. This growth has brought with it artificial intelligence, which is nothing more than the autonomous growth and learning of a computing machine.<sup>2,3</sup> The potential of this technology may be attributed to its ongoing updates and its capacity to adapt to users' needs

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based on newly incorporated data this could suggest a process of iterative revision or self-learning.

In the medical field, innovative technologies have transformed the way care is provided, creating increasingly artificial environments in which direct intervention by the human physician is diminished. Although in the field of allergy and clinical immunology these technologies have been limited, over the years' different applications and tools have emerged that participate more actively in the management of patients and their clinical records. Digital platforms such as MASK-air, Pollen Wise, and PO-SCORAD have enhanced medical practice by supporting patient education, symptom tracking, and empowerment. However, uptake remains limited, for example, MASK-air has been downloaded by about 73,000 users, but only two-thirds have used it at least once. This highlights challenges in awareness and acceptance, similar to those faced with treatment adherence.

These advances bring us closer to a future where technology will play a leading role in healthcare, redefining traditional models of care and attention. However, there are concerns regarding the use of technology such as data privacy, transfer of patient data to third parties, legal loopholes, and so forth.

## HISTORY OF ARTIFICIAL INTELLIGENCE: FROM THE "EARLY DAYS"

The story begins in 1842, when the British mathematician known as Ada Lovelace, created the first algorithm that was solved by a mechanical computer; after this discovery Ada Lovelace mentioned that in the future the machine would not only solve mathematical problems, but would perform much more complex operations or tasks. In 1921, the term "robot" was created, which means hard work; under this concept was born the "Three Laws of Robotics" created by author, Isaac Asimov, in his short stories of the 1940s, and the text continues to be widely referenced. Asimov's laws established that: (1) A robot may not harm a human being, or, through inaction, allow a human being to come to harm. (2) A robot must obey the orders given to it by human beings, except where such orders would conflict with the First Law. (3) A robot must protect its own existence, as long as

such protection does not conflict with the First or Second Law.<sup>4,5</sup>

However, it was not until 1956 that the term "Artificial Intelligence" (AI) was used for the first time at a conference at Dartmouth College, United States of America. In 1966, the world's first chatbot called ELIZA was created, developed by Joseph Weizenbaum, which had the ability to communicate with humans without the need for programming in code. But, it was not until 1996, when the potential of this technology was identified when the super-computer Deep Blue beat the world champion, Gary Kasparov, in a chess game. Already in 2014, a computer bot deceived more than 100 judges in the Turing test, where it pretended to be a 13-year-old boy; this gave us a perspective that even a machine can create its own personality<sup>4,6</sup>

There are different types of AI, the first known as "narrow" or weak, which only works in limited contexts, but can perform its tasks perfectly; the second is called "general", where there is the ability to solve any type of problem, with unlimited adaptation (Table 1).<sup>7</sup>

## BIOETHICS

Bioethics consists of the analysis of human behavior in the life and health sciences, based primarily on moral values and principles. It is essential to include bioethics in the training of health professionals since it is necessary for addressing complex medical problems. In turn, it promotes attitudes and behaviors that improve the doctor-patient relationship.<sup>8,9</sup>

In 1974, the National Commission for the Protection of Human Subjects of Biomedical Behavioral Research was conducted in the United States, whose objective was to create the basic ethical principles of research on humans. It was not until 1978 that the Belmont report was published, where the following principles were distinguished—respect, beneficence, and justice—which were merely used for human research issues. A year later, in 1979, the authors Tom L. Beauchamp and James F. Childress published the book "Principles of Medical Bioethics", where 4 principles directed to healthcare ethics are distinguished: non-maleficence, beneficence/charity, autonomy, and justice (Table 2).<sup>10,11</sup>

Type of AI	Definition	Medical Applications
<b>Narrow (weak)</b>	Designed for specific tasks and contexts	Diagnostic imaging, chatbots for quick consultations, prediction of specific diseases.
<b>General (strong)</b>	Able to learn and solve any problem with unlimited adaptation.	Not fully implemented; focus on research and simulations to emulate general human skills.
<b>Machine learning</b>	It allows machines to learn without specific programming.	Precision medicine, diagnosing diseases based on complex patterns of clinical data.
<b>Natural language processing (NLP)</b>	Processes and analyzes human language to interact or generate text	Creation of clinical notes, consultation transcriptions, automatic generation of medical reports.
<b>Physical robots</b>	Machines that perform physical tasks assisted by AI.	Robotic surgeries (eg, Da Vinci system), reduced surgical complications and greater precision.

Table 1. Types and applications of artificial intelligence in medicine

1. Non-maleficence:

It is based on the classic maxim of *primum non nocere*, which seeks not to cause any type of harm to the person being cared for. It should not be considered in isolation since there are medical procedures that can put the patient at risk or cause some type of harm; however, it is justified by the benefit they generate.<sup>10-12</sup>

2. Beneficence/Charity

It consists of preventing or alleviating harm, granting benefits; in other words, acting to seek the greatest good and well-being of the person being cared for. There are 2 types of beneficence,

positive and utility; where the first requires giving benefits while the other seeks a balance between benefits and harm. It is linked to the moral standard of “promoting the good” and is linked to quality services, respectful care, avoiding excessive therapy and respecting the beliefs of those receiving the services.<sup>10-12</sup>

3. Autonomy

Each person can make his or her own decisions, based on his or her beliefs, interests and desires. Autonomy is based on 2 basic principles, freedom, where there is independence from external influences and agency, where there is a capacity for intentional action. For an autonomous decision to

Principle	Definition	Key Aspects
<b>No maleficence</b>	Avoid causing harm, “First of all, do not be ignorant.”	Considers risks justified by benefits. It is not applied in isolation (treatments with necessary side effects).
<b>Charity</b>	Avoid harm, seeking the well-being of the patient.	Types: Positive (providing benefits) and utility (balance between benefits and harms).
<b>Autonomy</b>	Ability of the individual to make his own decisions	It requires freedom, agency and understanding.
<b>Justice</b>	Equitable distribution of goods and services.	Ensure adequate access to resources. Seek fair and equitable medical care.

Table 2. Bioethics key concepts

exist, 3 conditions must exist: acting intentionally, with understanding and without influences that determine his or her action.<sup>10-12</sup>

#### 4. Justice

Impartial, equitable and appropriate distribution in society. It is based on the moral norm of giving everyone what they need; in such a way it is necessary to have the necessary goods and to make an adequate distribution of them in order to guarantee appropriate health care.<sup>10-12</sup>

## RESPONSIBILITY AND ARTIFICIAL INTELLIGENCE

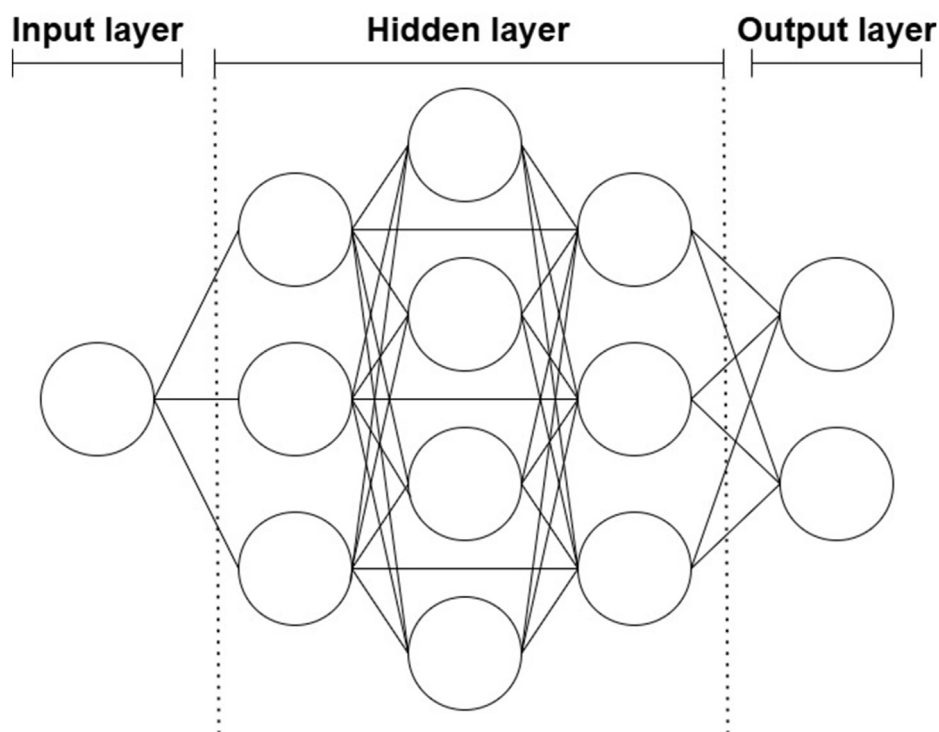
One of the most widely used applications of AI in medicine is the use of predictive algorithms, which have shown good results;<sup>3</sup> however, how certain are we that they are not free from errors, thus needing possible human-intervention or even other AI intervention.

And this is where the question comes in: who will take civil responsibility? Medical staff could simply trust the process or select the wrong algorithm, thus

legal consequences are directed to them, and not to others; however, if this algorithm is auto sufficient by itself, who is the real culprit? This is a key question to be able to advance to the next step in the evolution of the use of AI or is it a lock to leave the overuse of these technologies at this point.<sup>13</sup>

There is also something called “the black box” in artificial intelligence algorithms, this happens when the algorithm reaches a conclusion which cannot be explained by any human. This dark side of AI derives from deep neural networks (Fig. 1) and the behavior of thousands of simulated neurons, organized in dozens or even hundreds of interconnected layers that, as humans, we cannot interpret or reason adequately to find the way in which the AI reached a certain conclusion.<sup>13</sup>

An example of this use and responsibility is the software “Watson for Oncology”, which was developed by International Business Machine (IBM) using an architecture called “Deep QA” that allows analyzing large amounts of data and connecting genomic and medical data to personalize treatments using databases from more than 300 oncology medical journals. However, IBM prefers



Architecture of an artificial neural network composed of an input layer, two hidden layers, and an output layer. Each neuron applies a weighted sum of its inputs, adds a bias, and passes the result through an activation function. Weight adjustments during training allow the network to learn complex data representations [11].

Fig. 1 Schematic representation of a multilayer neural network.

to use the term “augmented intelligence” or “cognitive business platform” and decide clinical outcomes with evidence based medicine principles made by the physician in charge.<sup>14</sup>

In the case of Watson for Oncology, the medical responsibility continues to be that of the treating physician, since this is not a general AI, but rather specific to the tasks assigned by the programmer to facilitate the diagnosis and treatment of the physician. However, this is not exempt from possible errors on both sides, the AI and the treating physician.<sup>14</sup>

## MEDICINE AND ARTIFICIAL INTELLIGENCE

Over the years, biomedical engineers have implemented tools that learn techniques autonomously; this with the aim of improving the clinical process and efficiency. The available information that exists in medicine is too broad, the purpose of AI with this information is to recognize patterns that can predict the patient’s long-term health. However, as previously mentioned, when this diagnosis is reached, the machine cannot clearly explain why this conclusion is reached, which is why it is defined as “the black box of medicine”.<sup>15,16</sup>

“The black box of medicine” has great possibilities due to its potential to provide prognoses, diagnoses, image interpretation and therapeutic management. An article was recently published in the *New England Journal of Medicine*, where the possibility that all these advances in technology could displace and subsequently replace pathologists and radiologists is mentioned; however, data variation within different populations, thus patterns will vary between countries, even when same ethnicities are compared.<sup>13</sup> The World Health Organization (WHO) recognizes the potential of AI to improve health in different areas. AI could transform the healthcare sector thanks to the increasing availability of data and advances in analysis, benefiting patients and health professionals.<sup>2,17</sup>

## DOCTOR-PATIENT RELATIONSHIP

The implementation of AI in medicine has the potential to improve care quality, reduce errors, and enhance patient satisfaction. However, there is concern that healthcare purchasers may use it

primarily to shorten clinician-patient interaction time, which could weaken the doctor-patient relationship. A more balanced approach may lie in “blended care,” where clinicians use AI as a supportive tool to optimize outcomes. However, there are arguments that the implementation of these technologies may lead to dehumanization as they could make medicine a more linear and mechanized process.<sup>18</sup>

Clinical applications of AI have implications for relationships in healthcare. Potential benefits for patients include freeing physicians from routine and largely administrative tasks, which are currently not automatized efficiently, allowing them to focus more on the humanistic aspects of care, such as communication and healing. Whereas potential adverse effects include impaired communication, loss of trust, or conflicting decision-making, especially if there are discrepancies between the advice provided by the AI and that of the health care professionals, resulting in removal of professional autonomy. Addressing this point requires attention to detail, as the potential impact varies depending on the type of AI.<sup>19</sup>

Research has shown that patients prefer human doctors for diagnosis, screening and treatment; however, AI acceptance may depend on the specific features, as well as how choices are made and differences may exist between specific ethnic groups.<sup>20</sup> For example, in African American and Latino communities in Arizona, a mix of caution and skepticism was observed, due to concerns about equity and potential human detachment in care.<sup>21</sup> This results suggests that clinical decisions supported by AI should be transparent, in their methods, alternatives and understandability, thus could lead to more trust in AI intervention.

Patients have mixed opinions about the use of chatbots in healthcare. In one study, it was found that while some users valued their usefulness for simple tasks such as scheduling appointments or receiving reminders, there was significant mistrust in discussing more complex tasks or indeed anything more complex than arranging an appointment time. The main barriers were fears over data privacy and the perception that chatbots lack empathy and personalization. This emphasizes the need to improve the user interface and ensure data security to encourage uptake.<sup>20,21</sup> In this context, the question arises: can

robots elicit empathy? Recent studies in human-robot interaction (HRI) suggest that factors such as robot gender and anthropomorphic design significantly influence emotional contagion, a key component of empathy. These findings offer valuable insights for developing more emotionally engaging and socially acceptable robotic interfaces.<sup>22</sup>

## REGULATION

In the United States, medical technology is usually regulated by the Food and Drug Administration (FDA); however, since it is a “black box”, it is very difficult to understand the algorithms by which a medical conclusion is reached. Assuming conducting controlled clinical trials could be regulated by the FDA or ethic committees it would be a challenge due to the possibility of creating personalized algorithms, which would be too complex to understand.<sup>15</sup> Recently, in 2020, the WHO together with the Focus Group on AI for Health (FG-AI4H) created regulatory standards to ensure the safety and effectiveness of AI in the medical field. These standards include the following: documentation and transparency; risk management and life cycle approaches in the development of AI systems; intended use and analytical and clinical validation; data quality; privacy and data protection; and participation and collaboration.<sup>17</sup>

## PATIENT INFORMATION

Patient care is undergoing changes over time, from a generalized approach to something more personalized. Due to the latter approach, a large amount of information is obtained with the purpose of improving patient care. However, there is doubt about who owns this information, especially when there is the intervention of external factors such as AI, which is sometimes in charge of processing all this information and drawing new conclusions.<sup>16</sup>

## PROBLEMS ARISING

When dealing with medical information, particularly in digital environments, sensitive data of patients such as history of substance use or other health conditions may be involved. This raises concerns regarding data governance and ethical handling, especially with the use of AI. This is one of the major challenges that AI faces: who has access

and processes all this data, and what guarantees that such information remains confidential.<sup>23,24</sup>

While AI systems may improve efficiency and patient-centered care from a technical perspective, it is crucial to acknowledge that medicine is still, to a large extent, an art. Clinical reasoning often relies on human judgment, contextual understanding, and the ability to detect unspoken cues or emotional undertones. How will AI systems interpret what patients are unwilling or unable to disclose? And how will they navigate the subtle, intuitive aspects of medical practice that go beyond structured data?

## AI INTERVENTION

In healthcare, AI improves the patient-centric approach; by analyzing all the information provided, it is able to personalize the care received. Therefore, this results in early, accurate and better diagnoses. The automation of this data allows doctors to focus more on patient care.<sup>25-28</sup>

## TYPES OF AI RELEVANT TO HEALTH

Year after year, AI has an increasing impact on medicine, as there are cases where AI is even more effective in various fields such as diagnosis, treatment or surgery.<sup>29,30</sup> Some examples are discussed below.

### Machine learning

This branch of artificial intelligence allows the machine to learn to perform specific tasks without being specifically programmed for them. In healthcare, the most common application of traditional machine learning is precision medicine, which predicts which treatment protocols are most likely to be successful for a patient based on various patient characteristics and the treatment context. More advanced forms, such as deep learning, use complex neural networks with thousands of features to predict outcomes, such as in imagology by analyzing medical images to identify cancerous and other patterns features not easily visible to the human eye.<sup>31,32</sup>

Not only that, but in the educational context, AI has great potential to optimize the process of systematic reviews. If an algorithm is developed to analyze various databases with their specific inclusion and exclusion criteria, it is possible to extract key information from the included studies.

Furthermore, there is the possibility of autonomously detecting biases, thereby achieving more precise and reproducible work.

### Natural Language Processing

Natural Language Processing (NLP) includes applications such as speech recognition, text analysis, translation, and other language-related objectives. In healthcare, dominant applications of natural language processing involve the creation, understanding, and classification of clinical documentation and published research. NLP systems can analyze unstructured clinical notes about patients, prepare reports (eg, on radiology and anatomopathology examinations), transcribe interactions with patients, and perform conversational artificial intelligence.<sup>31</sup>

### Physical robots

Robot-assisted surgery represents the latest in technological advancements and is being applied to the surgical management of patients. The current concept of robotic surgery involves performing surgical procedures using small, articulated instruments that are attached to a robotic arm. Robotic surgery has been shown to reduce hospital stay, decrease complication rates, and allow surgeons to perform more precise tasks compared to traditional approaches of laparoscopy and open surgery.

The market is currently dominated by the da Vinci system, with approximately 5000 active systems performing over 1 million robotic surgeries each year. With the incorporation of artificial intelligence into surgical robotics, it will undoubtedly improve the accuracy of surgeries while minimizing the *trans*-surgical risks associated with surgical techniques.<sup>33,34</sup>

There are disadvantages to using surgical robots such as the robotic platform requires larger operating rooms to accommodate the robotic arms, consoles, and computer towers. Another concern is the loss of tactile sensation, combined with the strength of the robotic arms, which could lead to technical errors, longer operating times, and steeper learning curves.<sup>35</sup>

In the context of robots and their applications in allergies, their use in skin tests supports the interpretation of skin responses (wheel and flare), such as erythema or induration, with greater objectivity,

minimizing human bias. On the other hand, in molecular tests, they can identify complex patterns in genetic or molecular markers associated with particular, namely severe reactions or conditions. These technological advancements enhance diagnostic accuracy, personalize treatments, and prevent complications.

### Informed consent

Currently, there are ethical issues regarding that the informed consent and the use was obtained in the use of AI; this is particularly true in the use of clinical tools, as it is unknown whether it should be mentioned that these tools are being used and/or the information that should be provided. Currently, there are no laws, in the European Union or in countries such as the United States and in South Korea, that specify the use of informed consent.<sup>36-39</sup>

From an ethical perspective, it can be argued that patients should be informed about the use of AI in their healthcare. Muller et al argue that if AI is involved in decision-making, patients should be informed.<sup>40</sup> Kiener highlights 3 reasons for informed consent: risk of cyberattacks, systematic biases, and mismatches between AI assumptions and patients' context.<sup>41</sup>

The patient perspective has been neglected. The patient-based standard requires disclosing information that a reasonable person in the patient's position would consider important. In contrast, the physician-based standard focuses on what a professional would disclose in similar circumstances.<sup>42,43</sup> This is why the patient perspective is essential, as their information needs can help develop more effective protocols. Despite the recognition of the value of empirical research on patients' views regarding the use of AI in medicine, what information they consider crucial for making treatment decisions has not yet been explored.<sup>44</sup>

## AI IN ALLERGOLOGY

The potential benefits and usage of AI in allergy and immunology offer a unique approach for understanding and managing allergic diseases. AI has the potential to improve diagnostic accuracy and expand therapeutic options by predicting different disease trajectories. Although this technology is still

in its early stages and its full potential remains uncertain,<sup>45</sup> studies have shown that AI chatbots can assist in diagnosis, personalize treatment plans, and identify distinct disease phenotypes. Furthermore, AI can enhance human intervention by enabling more accurate and timely diagnoses, allowing for better treatment decisions and differentiating between allergic and irritant reactions.<sup>45,46</sup> Despite AI potential in allergy, human intervention remains irreplaceable, elements such as empathy, cultural competence and communications are not easily

achievable by AI machines. AI may assist in diagnostics or treatment planning, but it cannot replicate the reassurance, ethical judgment, or compassion offered by a skilled healthcare professional [Fig. 2].<sup>47</sup>

### AI usage for skin testing

We asked an AI platform (ChatGPT 4.0) to generate an image of skin testing and how it would interpret it (Figs. 3-4). Fig. 3 was generated with the following command “make an image of how



Fig. 2 Different examples of patient accessible AI tools in allergy.

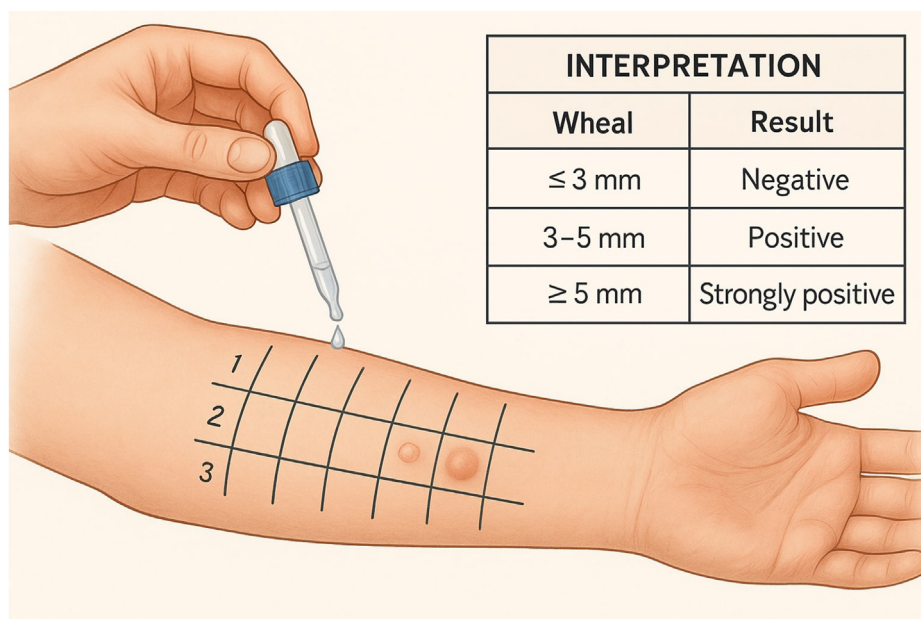
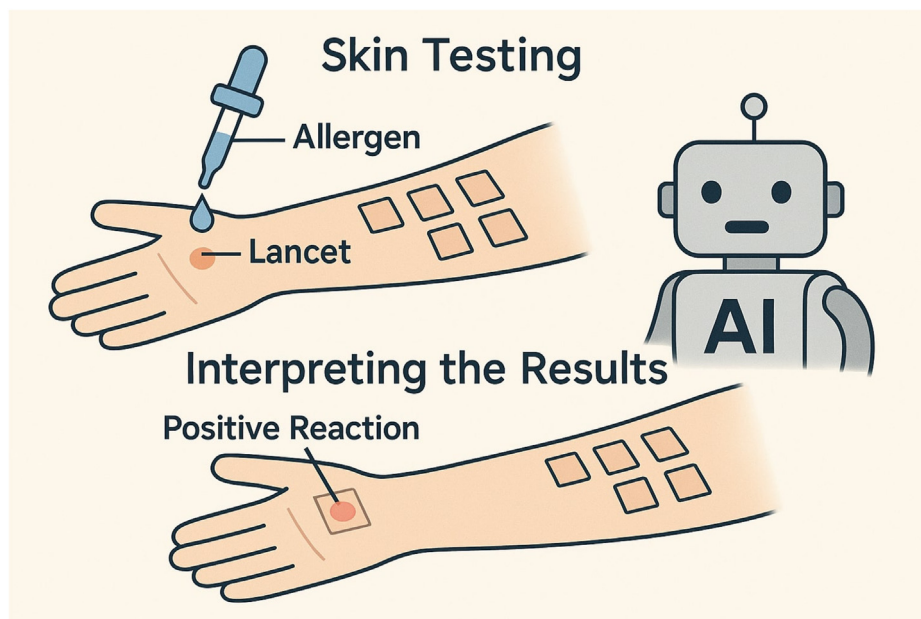


Fig. 3 Graphic image generated by artificial intelligence.



**Fig. 4** Graphical representation of a skin prick test (SPT) made by an AI online platform highlighting the procedure and interpreting a positive result.

Ethics	Ensure patient confidentiality and responsible use of information. Balance of human judgment and autonomous decisions. Development of unbiased models to ensure equitable health care outcomes.
Legal	Adhere to health care regulations. Obtain certifications and approvals from regulatory bodies. Define legal responsibility in cases of errors.
Socioeconomic	Ensure equitable access to AI-technologies. Conducting cost-benefit analyses. Prepare healthcare members through training and education programs.

**Table 3.** implications of AI in allergy and immunology

you would perform skin testing and its interpretation (allergy)” which was entered into the platform. The image represents a general but erroneous interpretation of the skin prick test interpretation. This error reflects the challenges in AI applications, which often stem from limitations in the training and validation datasets used by AI systems. Therefore, proper aggregation, curation, and continuous evaluation of these datasets are essential to ensure accurate AI recommendations and meaningful clinical outcomes.<sup>48</sup> Fig. 4 was generated with the same command.

### Implications of AI in allergy and immunology

Considerations of AI in medical practice follow the basic principles of autonomy, well-being, transparency and explainability, responsibility and

accountability, inclusiveness and equity, and responsive and sustainable systems. All these broad issues such as patient privacy and data security; however how are these addressed (Table 3)?<sup>45</sup>

However, all these implications have a drawback: economic disparity. Regional disparities in healthcare, economic and technological infrastructure make AI availability a resource limited to High-Income-Country only resource.<sup>49,50</sup> Therefore, is there truly widespread access for everyone?

### CONCLUSIONS

With the rapid evolution of technology in Medicine, specialists in allergy and clinical immunology are presented with an unprecedented opportunity

to enhance their professional practice. Artificial intelligence holds the potential to improve diagnostic accuracy, optimize treatment strategies, and personalize patient care with greater efficiency. While it is essential to address the ethical, legal, and data privacy considerations, embracing innovation with responsibility can lead to safer, more informed, and patient-centered approaches. By integrating technology thoughtfully, the specialty can advance toward a future where precision medicine and clinical decision-making are strengthened by the power of intelligent systems.

### Abbreviations

AI: Artificial Intelligence, IBM: International Business Machine, WHO: World Health Organization, FDA: Food and Drug Administration, FG-AI4H: Focus Group on AI for Health, NLP: Natural Language Processing, HRI: Human-Robot Interaction.

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Any additional data is available upon request to the authors.

### Author contributions

All authors contributed equally to this manuscript. Each team member was actively involved in the collection, analysis, and synthesis of information.

### Statement of ethics

No direct intervention with individuals or groups was conducted.

### Consent for publication

All authors give consent for publication.

### Declaration of competing interest

The authors have no conflicts of interest to declare.

### Artificial intelligence tools

The authors disclose use of ChatGPT 4.0 in creating Figure 3 and Figure 4, for demonstration purposes.

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