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# THE ROLE OF ARTIFICIAL INTELLIGENCE IN ALLERGOLOGY AND IMMUNOLOGY: FROM DIAGNOSIS TO PREDICTION

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***Abstract.*** Artificial intelligence (AI) and machine learning (ML) are rapidly transforming the field of allergy and immunology, offering innovative solutions for diagnosis, optimization, and personalization of patient care and treatment. This review examines current applications of AI in clinical allergy practice, ethical considerations, patient-centered technologies, educational requirements, and future directions. Based on a systematic literature search in PubMed, which included 19 relevant articles published between 2022 and 2025. We analyzed the integration of AI tools into natural language processing systems, clinical decision support algorithms, mobile health applications, and prognostic models. Although AI demonstrates significant potential in increasing diagnostic accuracy, personalizing treatment strategies, and improving patient outcomes, critical challenges remain regarding data privacy, transparency, clinical validation, and professional training. The emergence of explainable AI and digital twin technology are promising directions for precision medicine in allergology. However, successful implementation requires close attention to ethical frameworks, compliance with regulatory requirements, and preservation of human clinical expertise in patient care.

***Key words:*** artificial intelligence, machine learning, allergology, immunology, clinical decision support, digital health.

## Introduction

The integration of artificial intelligence (AI) and machine learning (ML) technologies into medical practice has been actively underway in recent years. In the fields of allergy and immunology, these technologies are improving traditional approaches to diagnosis, treatment, and patient management [9]. AI systems can analyze vast amounts of complex data, detect subtle patterns invisible to the human observer, and provide decision support, which increases clinical accuracy and efficiency.

Allergic diseases affect approximately 30–40 % of the world's population, with their prevalence increasing over the past decades. The complexity of allergic conditions, which include numerous potential allergens, diverse clinical manifestations, and variable patient responses, creates an ideal environment for the application of AI. ML algorithms can process immunological data, environmental factors, genetic information, and clinical histories to generate inferences that help develop personalized treatment strategies.

In recent years, there has been significant progress in the application of AI in various medical specialties, and allergy is no exception. Natural language processing (NLP) tools optimize clinical documentation [17], chatbots provide patient training and triage [1, 6], predictive algorithms identify at-risk groups [16], and mobile applications allow for real-time symptom monitoring [2, 18]. However, along with these advances, important questions arise regarding data security, algorithmic bias, clinical validation, and the appropriate balance between technological assistance and human experience [7]. This review **aims to provide a comprehensive overview** of current applications of AI in allergy and immunology, exploring both opportunities and challenges. We have attempted to assess the latest evidence regarding clinical tools, diagnostic systems, patient-centered solutions, ethical considerations, educational needs, and future directions.

## Methods

### *Literature Search Strategy*

The literature review was conducted using the PubMed database to identify relevant publications on artificial intelligence applications in allergology and immunology. Two primary search strategies were employed:

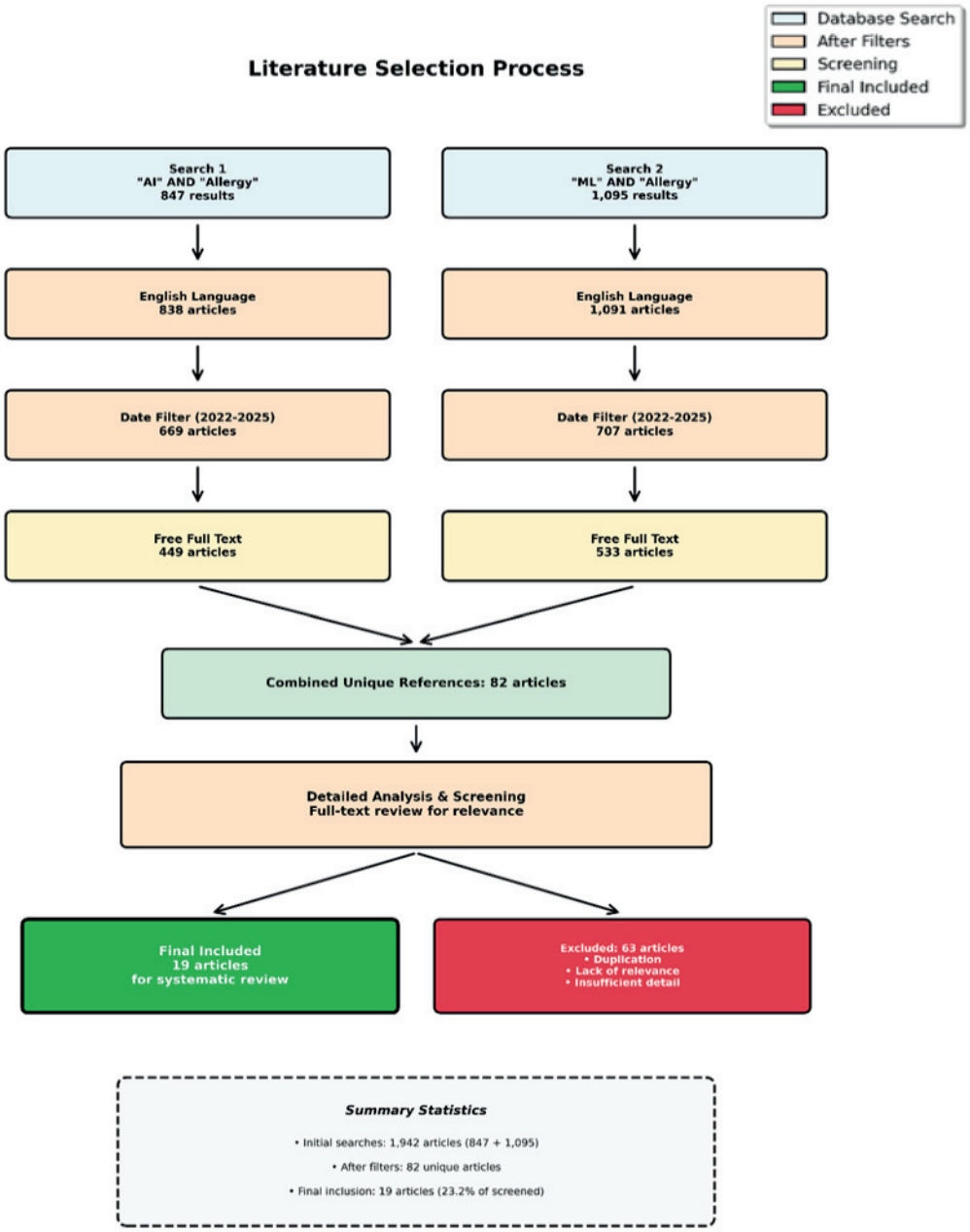
Search 1: "Artificial Intelligence" AND "Allergy" – This search yielded 847 total results. After applying filters for English language publications (838 articles) and restricting the publication date to January 1, 2022 through September 8, 2025 (669 articles), we identified 449 articles with free full text availability.

Search 2: "Machine Learning" AND "Allergy" – This search produced 1,095 total results. Following the same filtering criteria for English language (1,091 articles) and publication dates (707 articles), 533 articles with free full text were identified.

***Selection Criteria and Data Extraction***

The combined searches generated 82 unique references. Each article underwent detailed analysis to assess relevance to the review objectives. Articles were included if they: (1) focused on AI or ML applications in allergology or clinical immunology; (2) described clinical tools, diagnostic systems, or patient care applications; (3) addressed ethical, educational, or implementation aspects of AI in allergy practice; and (4) provided sufficient methodological detail or clinical evidence.

After applying these criteria, 19 articles were determined to be fully relevant to the review topic (Picture 1). The remaining articles were excluded due to duplication across searches, insufficient focus on allergology-specific applications, lack of clinical relevance, or inadequate detail regarding AI methodologies or outcomes. Data extraction focused on AI tool types, clinical applications, performance metrics, ethical considerations, and practical implementation factors.




***Picture 1. Literature selection process.***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## AI Tools in Clinical Allergy and Immunology Practice

### *Natural Language Processing and Clinical Documentation*

Natural language processing is one of the most directly applicable AI technologies in clinical allergy practice [9, 17]. NLP systems can extract structured data from unstructured clinical records, automate documentation tasks, and improve the accuracy and completeness of medical records. These capabilities address long-standing challenges in clinical workflow efficiency and data quality.

Recent studies show that NLP tools can significantly improve clinical documentation by automatically extracting key information from patient interactions [17]. These systems analyze spoken language, identify clinically relevant terms, and populate electronic medical records with structured data. This automation reduces the documentation burden on clinicians, potentially freeing up more time for direct patient interaction and clinical reasoning.

Advanced applications of NLP in allergy can detect patterns in large patient populations by analyzing electronic medical records [12]. These systems can detect comorbidities, track treatment responses, and identify patients who may benefit from specific interventions. However, language barriers still exist, and the use of these technologies remains limited in many countries.

### *AI-based chatbots and virtual assistants*

AI-based chatbots, including big language models such as ChatGPT, Grok, Gemini, are becoming valuable tools in allergy practice [6]. These systems can perform a variety of tasks, including triage of patients, pre-consultation documentation, appointment scheduling, and answering frequently asked questions about allergic conditions.

Studies evaluating the effectiveness of ChatGPT in allergy contexts reveal both promise and limitations [1, 8, 20]. The system can provide generally accurate information about common allergic diseases such as asthma, explaining symptoms, triggers, and basic treatment principles [8]. However, there are significant concerns about the depth of information provided, the lack of references and the occasional provision of incorrect or potentially harmful advice. A study examining dietary advice for patients with food allergies found that while most recommendations were appropriate, some suggestions could be harmful if followed without professional supervision [14]. However, our recent study has shown that there is still a lack of information provided to patients in the form of answers to questions, which may influence their decision-making [1]. This variability requires careful supervision and highlights that AI tools should be operated under professional guidance [1, 15].

### *Clinical Decision Support Systems*

AI-based clinical decision support systems are transforming approaches to allergy diagnosis and treatment [9]. These systems integrate patient data from multiple sources, including clinical history, laboratory results, environmental factors, and treatment response, to generate evidence-based recommendations.

Clinical decision support systems are particularly promising in managing complex cases involving multiple allergic conditions or comorbidities [12, 19]. Artificial intelligence algorithms can detect subtle patterns in patient data that indicate specific diagnostic possibilities or predict responses to treatment.

### *Predictive analytics and risk stratification*

Machine learning models are increasingly being used to predict disease outcomes and identify patients at high risk for complications [16]. Studies have developed algorithms to predict asthma exacerbations, allowing for preventive interventions that reduce emergency department visits and hospitalizations.

These predictive models analyze a variety of data, including clinical history, medication adherence, environmental factors, and physiological parameters, to generate risk scores. Studies have demonstrated the potential of machine learning algorithms in the early detection of primary immunodeficiency diseases [11]. By analyzing patterns in electronic medical records, these systems can identify patients who may benefit from specialized immunological testing, potentially reducing the diagnostic delays that often characterize these conditions.

## Patient-Centered AI Technologies

### *Mobile Health Applications for Symptom Monitoring*

Mobile applications can significantly improve allergy management by providing continuous, real-time monitoring of symptoms and environmental exposures [2, 18, 19]. These platforms allow patients to track symptoms, medication use, allergen exposure, and quality of life metrics through simple smartphone interfaces. The collected data provides valuable information to both patients and clinicians, supporting more informed treatment decisions.

Smartphone-based applications for objective symptom assessment are a significant step forward compared with traditional subjective reporting [18].

For example, applications that use smartphone microphones to count coughs in asthma patients provide quantitative measures that correlate with disease severity and response to treatment. This objective data improves communication between patients and healthcare professionals and allows for more precise adjustments in treatment.

The MASK-air platform demonstrates how mobile technologies can generate real-world evidence for the treatment of allergic rhinitis and asthma [3]. By collecting data from thousands of users across countries, the platform provides insights into treatment regimens, symptom control, and factors that impact quality of life. This real-world evidence complements traditional clinical trials and helps identify gaps between recommendations and actual practice. A similar app exists for patients with urticaria (CRUSE Urticaria Control app), which also helps assess symptom control and improve adherence to treatment.

***Diagnostic tools enhanced by AI***

AI is expanding diagnostic capabilities in allergology through advanced analysis of clinical data, laboratory results, and medical images [13]. ML algorithms can detect patterns in complex immunological test results that can be difficult for humans to interpret. These systems can offer diagnostic capabilities based on patterns of symptoms and test results, helping clinicians make more accurate diagnoses.

Explanatory AI methods are particularly important in diagnostic applications, as clinicians need to understand the reasons behind AI-generated suggestions [13]. Unlike "black box" algorithms that provide recommendations without explanation, explanatory AI systems show what factors contributed to their conclusions, allowing clinicians to assess the relevance and appropriateness of the recommendations.

## Ethical and Practical Considerations

***Data Privacy and Security***

The use of AI in healthcare has rightly raised significant concerns about privacy and data security [7]. AI systems require large data sets to train and operate, which necessarily includes sensitive patient information. That is why healthcare institutions must implement robust data protection measures, ensure informed consent for data use, and comply with legal regulations.

Patients are increasingly concerned about how their health data is used and who has access to it. Transparency about the collection, storage, and use of data is essential to maintaining patient trust. For their part, healthcare professionals must clearly communicate to patients the benefits and risks of AI-enabled solutions and respect patients' autonomy in data sharing decisions, avoiding categoricality.

***Clinical validation and regulatory oversight***

AI tools should undergo rigorous clinical validation before being widely adopted in healthcare settings [10].

Validation should demonstrate not only technical performance but also clinical utility and safety across patient populations and settings. Regulatory frameworks should balance the need to foster innovation with the need to protect patient safety. The regulatory landscape for AI in healthcare continues to evolve. Agencies such as the FDA are developing frameworks for approving AI-based medical devices, but many questions remain about how to regulate continuous learning systems that may change over time.

Professional medical and patient societies should also provide guidance on the appropriate use of AI and help establish best practices for implementation and monitoring.

***Maintaining Human Clinical Expertise***

A critical factor in implementing AI is to preserve and enhance human clinical expertise, not replace it [5]. The optimal model involves augmenting human capabilities with AI, with clinicians taking full responsibility for patient care decisions. Therefore, AI should be viewed as a tool that enhances efficiency and supports decision-making, not as a replacement for clinical judgment and the human elements of healthcare.

Training programs should emphasize critical evaluation of AI recommendations and maintain a focus on fundamental clinical skills.

## Educational Requirements for the AI Era

***AI Literacy for Healthcare Professionals***

As AI becomes increasingly integrated into clinical practice, medical education must adapt to prepare current and future allergists for this new landscape [5].

Medical training should incorporate AI literacy, teaching fundamental concepts of machine learning, data science, and algorithm interpretation without requiring students to become data scientists.

Understanding the capabilities and limitations of AI is essential for the appropriate and effective use of these tools. Continuing medical education must help practicing physicians understand and critically evaluate AI tools being introduced into their clinical environments [5]. This education should cover not only technical aspects but also ethical considerations, regulatory requirements, and strategies for maintaining patient-centered care in AI-augmented practice.


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Importantly, education should emphasize that AI is intended to enhance rather than replace human clinical expertise [5, 14]. The goal is synergistic collaboration where AI handles routine tasks and pattern recognition while clinicians focus on complex decision-making, patient communication, and individualized care planning.

***Patient Education and Engagement***

Patients also need to be educated about the capabilities and limitations of AI [1]. Being transparent about how AI tools work, what data they use, and how they make clinical decisions helps build trust and ensures informed participation in care.

Patients should understand that AI recommendations are decision-making tools that have to be reviewed by healthcare professionals. Healthcare professionals should be prepared to answer patients' questions and concerns about AI, including issues that have been addressed, the state of the algorithms, and the future role of human clinicians in their care.

**Future directions and emerging technologies**

***Digital twin technology***

Digital twin technology represents an exciting frontier in personalized medicine [4]. Digital twins are virtual copies of different patients that mimic chemical processes and predict responses to different treatments. In allergology, twin metrics can model how a patient's immune system might respond to different allergens or treatments, allowing for optimization of therapy within real-world clinical constraints.

This technology could revolutionize allergy immunotherapy by predicting optimal dosing regimens and identifying patients most likely to receive urgent treatment. Twin metrics can also simulate the effects of environmental or lifestyle changes.

***Integration with Internet of Things and Wearable Devices***

The integration of AI with Internet of Things (IoT) devices and wearable sensors promises comprehensive monitoring of patients with allergic diseases [19].

Wearable sensors can permanently measure vital parameters such as heart rate, respiratory rate and oxygen saturation, monitor allergen exposure, air quality and weather conditions. AI algorithms can integrate this diverse information to detect exacerbations, optimize medication timing and provide personalized recommendations. Smart home systems can automatically adjust environmental conditions based on predicted allergy triggers, without requiring wearable devices. These systems can also prepare patients for high-risk exposure and the development of symptoms in the future.

This proactive approach can significantly improve quality of life and lead to a reduction in the burden of the disease.

***Advanced multimodal analysis***

In future AI systems can integrate different types of information, including acoustic analysis, visual assessment, and sensor information, to provide a comprehensive objective assessment of allergic symptoms [4].

For example, AI can analyze cough sounds, breathing sounds, and facial expressions to determine asthma severity better than traditional AI reporting. Combined with environmental and chemical data, this multimodal approach can provide accurate, continuous monitoring of the disease.

**Pharmacogenomic integration**

Systems that integrate pharmacogenomic information with AI solutions can guide the selection of optimal treatments for individual patients [10]. By analyzing genetic variants that affect drug metabolism and immune responses, AI can determine which patients are most likely to benefit from certain drugs and which are likely to experience side effects. This personalized approach can improve treatment effectiveness while minimizing side effects.

**Conclusion**

Artificial intelligence is a transformative force in allergy and immunology, with the potential to revolutionize diagnosis, treatment, and patient care. Current applications demonstrate AI's ability to improve clinical documentation through NLP, support patient engagement through chatbots and mobile apps, improve decision-making through clinical support systems, and deliver personalized care through predictive analytics. Mobile health technologies facilitate patient self-management and continuous symptom monitoring, while machine learning models predict disease outcomes and identify patients at risk for complications. However, realizing the full potential of AI in allergy requires addressing significant challenges [7]. Ethical concerns around data privacy, algorithmic bias, and informed consent require careful attention and robust governance systems. The "black box" nature of many AI systems requires the continued development of explainable AI methods that provide transparency without compromising performance [13]. Regulatory pathways should evolve to accommodate AI technologies while

ensuring patient safety. Clinical validation standards should ensure that AI tools perform reliably across patient populations and settings [10].

Educational systems should adapt to prepare current and future physicians to practice in an AI-enhanced environment [5]. Medical curricula should include AI literacy, teaching fundamental concepts without requiring knowledge of data science. Continuing education should help practicing physicians understand and critically evaluate AI tools being implemented in clinical practice. It is important that education emphasizes that AI enhances, not replaces, human clinical experience, and that optimal care results from synergistic collaboration between AI and human intelligence.

Future developments promise even more sophisticated applications of AI [4]. Digital twin technology can enable personalized modeling and treatment optimization. Integration with IoT devices can enable comprehensive environmental and physiological monitoring [19]. Advanced acoustic and visual analysis can provide objective, continuous symptom assessment. Pharmacogenomic integration can help select optimal treatments for individual patients based on their genetic profiles [10]. These innovations have the potential to fundamentally change allergy treatment, enabling precision medicine approaches that were previously not possible. The way forward requires collaboration between multiple stakeholders [9,10]. Clinicians must be involved in the development of AI to ensure that tools meet real clinical needs, researchers must conduct validation studies. Ethicists and policymakers must develop frameworks that ensure the responsible use of AI. Patients should be involved in decisions about the deployment and use of data.

In conclusion, AI is a powerful force for the advancement of allergy and immunology, with the potential to increase diagnostic accuracy, personalize treatment, improve patient self-management, and accelerate research. However, this potential can only be realized through thoughtful implementation that addresses ethical concerns, supports human clinical expertise, ensures equitable access, and preserves patient safety and autonomy. As the field evolves, the goal should be for AI systems that complement, not replace, human capabilities, working in partnership with clinicians to provide patient-centered, evidence-based, and compassionate care. The future of allergology will likely include the active integration of AI tools into clinical practice, but success requires a focus on the ultimate goal: improving outcomes and quality of life for patients with allergic and immunological diseases.

## РОЛЬ ШТУЧНОГО ІНТЕЛЕКТУ В АЛЕРГОЛОГІЇ ТА ІМУНОЛОГІЇ: ВІД ДІАГНОСТИКИ ДО ПРОГНОЗУВАННЯ

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***Резюме.*** Штучний інтелект (ШІ) та машинне навчання (МН) швидко трансформують галузь алергології та імунології, пропонуючи інноваційні рішення для діагностики, оптимізації та персоналізації догляду за пацієнтами та їх лікування. Цей огляд розглядає сучасні можливості застосування ШІ у клінічній алергологічній практиці, етичні аспекти, пацієнт-орієнтовані технології, освітні вимоги та майбутні напрямки розвитку. На основі систематичного пошуку літератури в PubMed, який включав 19 релевантних статей, опублікованих у період з 2022 по 2025 рік, ми проаналізували інтеграцію інструментів ШІ в системи обробки природної мови, алгоритми підтримки клінічних рішень, мобільні медичні додатки та прогностичні моделі. Хоча ШІ демонструє значний потенціал у підвищенні точності діагностики, персоналізації стратегій лікування та поліпшенні результатів лікування пацієнтів, залишаються критичні виклики щодо конфіденційності даних, прозорості, клінічної валідації та професійної підготовки. Поява пояснювального ШІ та технології цифрових двійників є перспективними напрямками для прецизійної медицини в алергології. Однак, успішне впровадження ШІ вимагає пильної уваги до етичних принципів, дотримання регуляторних вимог та збереження людської клінічної експертизи в догляді за пацієнтами.

***Ключові слова:*** штучний інтелект, машинне навчання, алергологія, імунологія, підтримка клінічних рішень, цифрова медицина.

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**Джерела фінансування.** Робота виконувалась без жодної фінансової підтримки.

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