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# Artificial Intelligence-Driven Innovations in Allergy

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**SUMMARY**
Artificial Intelligence (AI) is transforming allergology by enhancing diagnostics, personalizing treatments, and optimizing patient management. From environmental forecasting to advanced diagnostics, AI leverages machine learning algorithms to analyze complex data, identify biomarkers, and predict allergic reactions. Despite its potential, challenges regarding data privacy, algorithmic bias, and integration into clinical workflows still need to be addressed. Interdisciplinary collaboration and ethical frameworks are essential to harnessing AI's benefits and redefining the future of care of allergic diseases.

**KEYWORDS:** Artificial Intelligence, Allergology, Machine Learning, Personalized Medicine, Environmental Monitoring, Diagnostic Innovations

## Introduction

Artificial Intelligence (AI) has become a game-changer in healthcare, addressing long-standing challenges and enhancing clinical outcomes across various specialties. In allergology, AI is offering unprecedented opportunities to improve diagnosis, personalize treatment, and streamline patient management. Allergic diseases, encompassing asthma, allergic rhinitis, atopic dermatitis, and food allergies, affect millions of people globally, pose significant public health challenges. The intricate nature of these conditions—marked by various triggers, individual variability, and environmental and genetic determinants—necessitates the implementation of sophisticated methodologies for their effective management. Machine learning (ML) and deep learning technologies are emerging as transformative forces in this field, possessing the capacity to scrutinize extensive data collections to reveal underlying patterns and formulate predictions. AI is reshaping allergology, contributing at different levels, from environmental monitoring to diagnosis, personalized treatment, and patient care. However, several challenges and ethical concerns are associated with AI integration in clinical practice. If one considers AI tools with human judgment, we can propose future directions for research and development in allergology.

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## ALLERGY FORECASTING AND ENVIRONMENTAL MONITORING

Allergy forecasting, which predicts allergen levels like pollen and mold spores, has become increasingly important in managing allergic diseases. Environmental monitoring systems, tracking weather patterns, airborne particles, and pollutants, play a critical role in this effort [1,2]. However, climate change has made it more challenging to maintain accurate pollen calendars. Shifting weather patterns and regional variations in climate effects have led to inconsistencies, complicating predictions of allergen exposure [3]. Looking ahead to optimizing these technologies to improve patient outcomes further and streamline clinical workflows, advancements in AI have improved the accuracy of forecasting models, allowing clinicians and patients to receive real-time alerts. These models integrate environmental monitoring with predictive analytics, accounting for broader environmental and climate factors. For example, applications like PolRam use ML to predict pollen levels in specific regions by analyzing weather data, achieving 90-95% accuracy. This technology allows users to take preventive measures, thereby reducing the risk of allergy flare-ups and improving public health [4]. Digital health is revolutionizing healthcare delivery by harnessing information and communication technologies, particularly mobile health (mHealth), to boost patient engagement and improve the quality of care, primarily through clinical decision support systems [5]. In allergology, digital tools like AllergyMonitor have shown impressive results in over more than a decade of use by patients with seasonal allergic rhinitis (SAR). Not only has patient adherence to therapy improved, but by correlating symptoms with pollen counts, these tools enable short-term symptom predictions at an individual level. This personalized approach dramatically benefits patients, maintaining a high adherence to daily symptom tracking (over 80%) for several weeks [6].

Similarly, AI has shown potential in asthma management. A recent study demonstrated that passive monitoring using environmental data can effectively predict asthma attacks for patients triggered by outdoor factors. This shift from active symptom tracking to passive monitoring can reduce patient burden while maintaining clinical accuracy [7]. Such innovations underscore the potential of AI to revolutionize allergy forecasting and disease management.

## AI-ENHANCED DIAGNOSTICS

One of the significant challenges in allergology is accurately and timely diagnosing allergic conditions. Although molecular diagnostics have improved this, challenges remain in correlating test results with clinical presentations [8,9]. The complexity of allergies, compounded by poly-sensitization, overlapping symptoms, and multimorbidities, often complicates diagnosis [10].

AI offers solutions to these diagnostic hurdles. ML algorithms can analyze large volumes of patient data, including genetic information, environmental exposures, symptomatology, and imaging, to identify patterns indicative of specific allergies. An interesting study highlighted the potential of using speech biomarkers to detect and categorize respiratory diseases through vocal recordings. The authors presented an AI-based system to analyze voice data using an articulatory speech task, which could be applied to identify specific asthma-associated features [11]. Convolutional neural networks-powered analysis of visible-spectrum and thermal images can enhance the interpretation and standardization of skin tests [12]. These technologies streamline diagnosis and empower clinicians with data-driven insights to improve decision-making.

Moreover, AI can assist in identifying novel biomarkers by analyzing genomic and proteomic data or developing ML-based modeling of the component-resolved diagnostic (CRD) multiplex array data, enabling earlier and more precise detection of allergic diseases [13] . At the same time, predictive models can forecast allergic reactions based on real-time data. AI and ML offer the potential to develop advanced predictive models and diagnostic tools that can help in the early detection and prevention of anaphylactic episodes, thereby reducing the risk of severe reactions and improving overall patient care [14]. Thus, integrating AI with comprehensive electronic health records further enhances diagnostic processes by providing real-time updates and fostering personalized treatment plans tailored to individual patient needs.

## PERSONALIZED MEDICINE AND TREATMENT OPTIMIZATION

AI may facilitate the creation of personalized treatment strategies by predicting patient responses based on genetic profiles, medical histories, and environmental factors. ML models can assess the efficacy of medications or immunotherapy protocols for each patient, optimizing treatment plans to maximize benefits and minimize side effects. Notably, AI is pivotal in addressing allergen the complexities of immunotherapy, a cornerstone in allergy treatment. Physicians face challenges in prescribing allergen immunotherapy, particularly in regions like Southern Europe, where high rates of polysensitization and cross-reactivity among multiple pollens coexist during the same season. To address these difficulties, the @IT2020 algorithm was developed, which is a clinical decision support system for SAR based on a three-step process: gathering clinical history and sensitization data, refining allergens through CRD, and using an electronic diary (eDiary) to match symptoms with pollination periods. This structured methodology significantly enhances the precision of allergen identification, leading to more effective prescriptions of allergen immunotherapy by allergy specialists and general practitioners[15]diagnostics based on retrospective clinical history and sensitization to whole extracts (SWE. The authors are finalizing a manuscript detailing the ML system integration to further automate and enhance diagnostic accuracy and appropriateness in allergy care.

## ETHICAL CONSIDERATIONS ANDCHALLENGES

While the potential of AI in allergology is immense, its implementation presents several pressing challenges. Foremost among these is data privacy. AI systems rely on extensive volumes of sensitive patient data, prompting significant concerns about confidentiality and security. Adherence to regulatory frameworks, such as the General Data Protection Regulation, is imperative to safeguard patient information. Furthermore, AI models are prone to the influence of algorithmic bias. When the training dataset does not represent heterogeneous populations, AI systems may yield biased outcomes, potentially resulting in inequity in the delivery of healthcare [13].

Additionally, the integration of AI into clinical workflows poses practical challenges. AI must complement, rather than disrupt, the patient-provider relationship, and maintain a patient-centered approach. To achieve this, clinicians need comprehensive education and training in AI applications, which should begin at the university level and continue through professional development programs. Establishing robust infrastructure and technological tools, particularly in public health systems, is also essential to ensuring the accessibility and scalability of AI-driven solutions. AI should complement, not replace, human judgment. Clinicians must maintain a patient-centered approach, using AI to enhance their expertise rather than overshadow it.

In addition, the transition from pediatric to adult care represents a critical phase in managing allergic diseases and asthma. As highlighted by Nagy et al., while AI holds immense promise for improving healthcare outcomes, there is a tangible risk that its development may exacerbate the therapeutic gap between pediatric and adult care[16]. Historically, children have been underrepresented in clinical trials and healthcare innovations, leading to suboptimal tools for pediatric care—a trend that must not be repeated in AI development.

AI systems could bridge this care transition by facilitating continuity and personalization of care plans. Pediatric allergic diseases often exhibit evolving clinical and immunological profiles that require dynamic monitoring. AI algorithms trained on pediatric and adult longitudinal datasets could support predictive modeling to anticipate disease progression and treatment responses during this transition. For example, machine learning tools have successfully predicted asthma exacerbations based on environmental triggers and patient history, which could be adapted to guide individualized treatment adjustments during adolescence [7]. However, as Nagy et al. cautioned, the need for more inclusion of pediatric data in AI training is a significant barrier [16]. Models developed predominantly with adult datasets may yield unreliable predictions when applied to younger populations due to differences in disease manifestations, immunological responses, and treatment sensitivities. A pertinent example includes AI models designed to detect pneumonia in adults, which underperformed significantly when applied to pediatric radiographic datasets[17]. This underscores the need for pediatric-specific datasets encompassing the care continuum from childhood to adulthood.

Proactive strategies are needed to ensure AI enhances the transition rather than widening disparities. These include advocating for policies that mandate pediatric representation in AI trials — similar to the Pediatric Research Equity Act for drug development — and fostering initiatives like PedsNET, which streamline the collection of pediatric data through learning health systems [18]. Additionally, developing AI-driven tools that integrate data from electronic health records across pediatric and adult care settings could ensure clinicians have a unified view of the patient's disease trajectory, facilitating better decision-making. In practical terms, AI-powered clinical decision support systems (CDSS) can help identify "transition milestones," such as shifts in treatment adherence, disease control, or psychosocial factors that often complicate care during adolescence. Augmented by AI, remote monitoring solutions have already shown efficacy in improving compliance and disease management in pediatric asthma [6] and could be leveraged to maintain continuity during this vulnerable period.

Ultimately, a collaborative and inclusive approach to AI development — one that prioritizes pediatric datasets, cross-disciplinary integration, and long-term monitoring — will ensure that the promise of AI benefits children transitioning into adult care.

## CONCLUSION

The future of AI in allergology is promising. Continued advancements will require interdisciplinary and collaborative efforts between data scientists, allergists, and technologists, as well as robust regulatory frameworks to ensure its ethical and safe integration into healthcare.

Future research should prioritize refining AI models to advance our understanding of the pathogenesis of allergic disease, improve predictive accuracy, enhance environmental monitoring, and explore new biomarkers for allergy diagnosis. This more profound insight into the biological mechanisms underlying allergies can pave the way for developing novel targeted therapies, enabling more effective and personalized treatments for allergic conditions. Thus, AI is poised to revolutionize allergology, offering new possibilities for improving diagnostics, personalizing treatments, and optimizing patient management. Nevertheless, a thoughtful exploration of ethical dilemmas, safeguarding data privacy, and the necessity for synergy between technological innovation and clinical wisdom is paramount. By cultivating a harmonious methodology, the healthcare sector can fully tap into the boundless capabilities of AI while upholding the essence of patient-focused care. As AI progresses, it will become indispensable in redefining the landscape of allergology, ultimately enhancing the experiences of patients grappling with allergic diseases.

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### Conflicts of interest statement

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## Author's contribution

AG and ST drafted and revised the manuscript for important intellectual content; all co-authors were actively involved in the discussion and critical review of the manuscript. All authors contributed to the article and approved the submitted version.

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