Taylor & Francis
Taylor & Francis Group

Journal of Medical Economics

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/ijme20

How AI is advancing asthma management? Insights into economic and clinical aspects

Ahmad Z. Al Meslamani

To cite this article: Ahmad Z. Al Meslamani (2023) How AI is advancing asthma management? Insights into economic and clinical aspects, Journal of Medical Economics, 26:1, 1489-1494, DOI: 10.1080/13696998.2023.2277072

To link to this article: https://doi.org/10.1080/13696998.2023.2277072

Published online: 11 Nov 2023.

JOURNAL OF MEDICAL ECONOMICS
2023, VOL. 26, NO. 1, 1489–1494
https://doi.org/10.1080/13696998.2023.2277072
Article 0198-RT/2277072

Taylor & Francis
Taylor & Francis Group

COMMENTARY

OPEN ACCESS Check for updates

How AI is advancing asthma management? Insights into economic and clinical aspects

Ahmad Z. Al Meslamani[a,b]

[a]College of Pharmacy, Al Ain University, Abu Dhabi, United Arab Emirates; [b]AAU Health and Biomedical Research Center, Al Ain University, Abu Dhabi, United Arab Emirates

ABSTRACT

Asthma, an increasingly prevalent chronic respiratory condition, incurs significant economic costs worldwide. Artificial Intelligence (AI), particularly Machine Learning (ML), has been widely recognized as transformative when applied to asthma care. This commentary investigates how AI and ML may improve clinical outcomes while alleviating some of the costs associated with asthma care. AI's powerful analytical abilities could usher in an unprecedented era of preventive measures, particularly by identifying at-risk populations and anticipating environmental triggers. ML shows promise for enhancing real-time monitoring, early detection, and tailored treatment strategies in paediatric asthma, potentially reducing hospitalizations and emergency care costs. Emerging AI-powered wearable technologies are catalysing a revolutionary shift in patient monitoring, providing proactive interventions. Although optimistic, this commentary highlights a gap in empirical studies evaluating the cost-effectiveness of AI in asthma care and stresses the need for larger datasets to accurately represent the economic benefits of AI solutions. Additionally, this paper emphasizes the ethical considerations surrounding data privacy and algorithmic bias, which are vital for the successful and equitable integration of AI into healthcare settings. This editorial underscores the urgent necessity of conducting thorough analyses to assess all economic implications, facilitate optimized resource allocation, and foster a nuanced understanding of AI/ML technologies in asthma management that may reduce costs to healthcare systems.

ARTICLE HISTORY
Received 6 October 2023
Revised 26 October 2023
Accepted 26 October 2023

KEYWORDS
AI; machine learning; asthma; prediction accuracy

JEL CLASSIFICATION CODES
A19; A1; A; A20; A2

Introduction

Asthma, a chronic respiratory condition marked by inflammation and airway constriction, affects an estimated 339 million people worldwide, as per the World Health Organization[1]. It also presents a notable economic challenge, with the Asthma and Allergy Foundation of America estimating its annual cost at $80 billion[2]. Further emphasizing this financial strain, the average cost for outpatient asthma treatment is pegged at $1,291.20[3].

The implications of asthma extend well beyond the clinical sphere, significantly impacting the economic domain. Health systems, medical institutions, and patients grapple with extensive financial burdens, stemming from ongoing treatments, hospitalizations, premature mortality, and productivity losses due to missed work and school days[4].

In this context, the advent of Artificial Intelligence (AI), especially its major subset Machine Learning (ML) in healthcare signifies a transformative phase. Research posits AI as a potent tool, adept at swiftly analyzing vast datasets, discerning intricate patterns, and offering predictive insights. Such capabilities hold the potential to revolutionize asthma management[4,5]. However, a closer examination exposes a research gap: while the transformative capability of AI across asthma care, from screening to patient satisfaction, is evident, the current research landscape is somewhat sparse, occasionally plagued by small sample sizes or questionable data quality[4].

Integrating ML into asthma care introduces groundbreaking clinical benefits. Its predictive capabilities foster timely interventions, potentially curtailing hospitalizations. Moreover, its capacity for early detection dovetails with tailored treatment strategies, amplifying therapeutic success. Innovative algorithms signal a shift towards even more personalized treatments, especially in pediatric asthma. Within clinical settings, these sophisticated models expedite diagnosis, facilitating swift and tailored treatments. ML's robust analytical strengths allow it to pre-empt potential asthma triggers, analyzing both environmental and patient-centric data and recommending proactive actions. Continuous monitoring via ML champions a proactive stance, ensuring immediate treatment modifications and reinforcing evidence-based decisions. AI platforms not only educate patients but also pinpoint medication discrepancies, facilitating timely interventions. In healthcare, AI's prowess in resource optimization forecasts patient influx triggered by seasonal or environmental changes. Furthermore, AI's transformative

CONTACT Ahmad Z. Al Meslamani Ahmad.almeslamani@aau.ac.ae College of Pharmacy, Al Ain University, Abu Dhabi, United Arab Emirates

potential in clinical trials, especially concerning remote patients, holds significant promise.

Therefore, this editorial aims to shed light on the potential clinical and economic consequences of incorporating AI tools, particularly machine learning, in asthma care. It discusses how these technologies might foster cost-savings and elucidates the mechanisms driving these effects. Furthermore, the editorial provides clinicians with insights on effectively integrating these tools to improve patient outcomes.

AI's role in identifying at-risk populations in asthma care

Artificial Intelligence has demonstrated significant potential in identifying individuals at an elevated risk for asthma. By assessing a multitude of factors, AI stands at the vanguard of preventive healthcare measures. Genetic predispositions are instrumental in determining asthma susceptibility. Using the vast genetic data repositories available to AI systems, these systems can discern patterns linked to an increased propensity for asthma development. Concurrently, environmental factors are crucial in both the onset and exacerbation of asthma. The capability of AI to analyze geospatial data, historical pollen counts, and air quality reports is invaluable in supporting treatment initiatives. Such analysis can pinpoint regions with heightened asthma occurrences, thereby informing residents of potential risks. Additionally, AI's sophisticated algorithms can efficiently sift through patient records, identifying instances of respiratory illnesses or allergies that lead to frequent hospitalizations, as well as admissions due to respiratory challenges.

The role of AI in predicting environmental conditions

A systematic review and meta-analysis revealed that ML prediction models can successfully forecast asthma exacerbations using various ML methods such as Logistic Regression, Boosting, and Random Forest. An analysis encompassing 11 studies and 23 prediction models yielded an overall pooled area under the curve (AUROC) value of 0.80, indicating excellent predictive performance. Among all the methods employed for prediction, the boosting method excelled with an AUROC of 0.84; models utilized variables such as systemic steroid use, short-acting beta 2-agonists use, emergency department visits, age, and exacerbation history as key predictors[4,6]. Another study has shown that, when AI is coupled with extensive and well-characterized datasets, it can yield models designed to enhance clinical practice for chronic illnesses like asthma[6]. The utilization of AI is anticipated to facilitate better care delivery, aiding in everything from asthma screening and diagnosis to management. Additionally, a particular study employed a LightGBM prediction model to predict non-severe asthma exacerbations, achieving a sensitivity of 0.64 and a specificity of 0.67[7].

AI and severe asthma

AI tools are emerging as significant trends in managing severe asthma, particularly within high-cost clinical groups, with the potential to notably transform care delivery and overall disease management[4]. AI and ML techniques are being increasingly utilized to classify patients based on various characteristics such as disease severity and phenotype, thereby enabling tailored management strategies[4]. An academic study highlighted the success of employing Random Forest algorithms to distinguish between pediatric patients with controlled and uncontrolled asthma using volatile organic compounds as biomarkers[4]. AI also facilitates the accurate diagnosis and management of asthma exacerbation episodes, which are major cost drivers for severe asthma care[8]. By mining large datasets for meaningful patterns, these technologies foster an enhanced understanding of asthma pathogenesis while monitoring patient conditions in real time, which could potentially reduce both the frequency and severity of exacerbations. Although data concerning the cost-effectiveness of AI in managing severe asthma within the most expensive clinical groups are limited, its potential to improve management and monitoring may lead to savings that ultimately translate to cost reduction. Effectively predicting and managing exacerbations could significantly reduce healthcare expenditures. AI and ML present promising, cost-effective management strategies for severe asthma, which, despite comprising only 5–6% of cases, accounts for a substantial portion of its direct expenses[8].

AI's limitations and considerations

AI tools in healthcare largely hinge on the quality and diversity of their training data. The efficacy of a model is contingent upon exposure to varied, relevant datasets that encompass diverse populations, a challenge often encountered in practice. If certain demographics or medical conditions are under-represented in the training dataset, the AI tool may exhibit biases or inaccuracies when projecting for these groups. Additionally, it is imperative to ascertain whether an AI's predictions are influenced or tailored to a specific health care management system. If so, its recommendations may not have universal applicability, potentially limiting its efficacy across diverse healthcare settings. In the context of asthma, if patient populations, such as various ages, ethnicities, or coexisting conditions, are not adequately mirrored in the training data for AI tool algorithms, the predictions may be skewed or incomplete. Moreover, if the tool's recommendations are largely predicated on the approach of a single health care management system, they might not be transferable across different protocols or settings.

Ethical considerations are also vital. The ethics surrounding data privacy and algorithmic bias in health technologies are of paramount importance, given their potential to perpetuate health inequalities. Biases within health data pose a substantial ethical threat to the application of machine learning in medicine[9], while algorithmic biases disadvantage certain social groups, affecting health equity (defined as all patients reaching their full health potential across all groups)[10]. The health risks stemming from COVID-19 have underscored long-standing inequities within the US healthcare system. Data have revealed an alarming disproportionate burden borne by communities of color, elevating health equity to a central topic in public policy discourse[11]. Implementing AI tools within healthcare necessitates that physicians meticulously evaluate its clinical utility and accuracy to avert exacerbating socioeconomic, racial, or gender biases within algorithms; clear data regulations must also be established to secure ownership, access, sharing, and monitoring of patient data[11]. Nonetheless, bias can pervade all stages of algorithm design, from study design and data collection through to algorithm selection, implementation, and dissemination, thereby perpetuating health inequalities through technology.

Discussion

This editorial examines both the economic and clinical implications of utilizing AI tools in asthma care. While the benefits are evident, we were unable to locate studies that specifically assess the cost-effectiveness of integrating AI tools into asthma management. Consequently, discussions on economic aspects in this editorial might draw from studies related to other diseases or settings.

Clinical implications

ML has demonstrated potential in predicting asthma exacerbations. A recent systematic review evaluating 23 models revealed a pooled AUROC of 0.80 (95% CI = 0.77–0.83)[6]. However, significant variability in these models' methodologies exists, complicating the comparison of results across studies and underscoring the need for standardization to ensure consistent outcomes and wider field applications.

In pediatric asthma research, ML has been utilized for prediction in only a few studies. Due to their limited clinical impact and suboptimal predictive accuracy, these models are not ideal for integration into electronic medical record decision support[12]. Notably, the Artificial Neural Network (ANN) and Support Vector Machine (SVM) stood out as top-performing algorithms in some ML predictions for pediatric asthma[12].

Efforts to identify asthma in hospitalized patients have led to rigorous evaluations of AI tools using electronic patient record data. Among the evaluated models, the CatBoost model was found to be the most effective, achieving an accuracy of 84.7% and an AUC of 90.9%[13]. Another study identified the Random Forest model as superior for asthma diagnosis, achieving a precision of 80.3%. This study emphasized the importance of attributes such as MEF2575, smoking habits, age, and wheezing symptoms. These insights offer valuable guidance for pulmonologists and tech professionals in refining diagnostic tools. However, it is important to note that these models primarily identify the presence of asthma without delving into its severity or suggesting treatments. There is also a risk of overfitting when employing multiple ML models and hyper-parameter optimization techniques, which might compromise their performance on new data. Additionally, these tools did not aid clinicians in completing medical records or conducting supplementary examinations.

ML is also emerging as a key approach in enhancing asthma monitoring. Traditional monitoring techniques often lack the capacity to offer real-time insights into disease progression and the customization of precision medicine. A recent innovative study introduced the use of electroencephalogram (EEG) signals for non-invasive asthma severity monitoring[14]. By integrating various artificial intelligence methodologies, including ensemble models and the XGBoost classifier, the research highlighted the potential of EEG signals for personalized home-based asthma monitoring, reducing the need for patient intervention.

AI integrated into wearable technology has catalyzed a paradigm shift in asthma care. Wearable devices equipped with a range of sensors facilitate continuous monitoring for patients. These sensors scrupulously track respiratory rates, pinpointing anomalies that might elude the untrained human eye. Vital signs, especially elevations in heart rate, often serve as harbingers of looming asthma attacks. Metrics such as skin temperature can also shed light on systemic reactions, potentially signposting an impending asthma episode. AI algorithms, endowed with unmatched processing capabilities, analyze this data stream in real-time. They can provide pre-emptive alerts to both patients and healthcare practitioners, possibly circumventing acute asthma attacks or subsequent hospitalizations. These prompt notifications enable healthcare professionals to intervene expeditiously, potentially forestalling more intensive and costly treatments down the line.

Recent studies assessed the potential of ML in distinguishing asthma phenotypes and endotypes[15,16]. Identification of these is paramount for elevating clinical care, enabling therapies tailored uniquely to individual needs, epitomizing precision medicine. A comprehensive grasp of asthma's manifestations, both clinically observable and pathophysiological, empowers clinicians to deliver precise diagnoses and craft individualized treatment plans. These insights spur the discovery of innovative therapeutic targets, bolstering treatment effectiveness. Understanding these dimensions, clinicians can introduce specific preventive measures to mitigate asthma onset or exacerbations. Healthcare providers can better support asthmatics by imparting knowledge on self-management, potential triggers, and lifestyle nuances. Embracing such a personalized approach enhances both health outcomes and the quality-of-life of asthmatic patients.

Economic implications

The paucity of empirical studies addressing the cost-effectiveness of AI in asthma care, while initially alarming, is justifiable upon deeper examination. The nascent integration of AI into healthcare is a primary factor. For instance, cardiovascular care has benefited from technological advancements for years, whereas AI's foray into asthma care is still in its infancy, necessitating more time for comprehensive long-term data collection. Asthma's intricate nature, which spans a gamut of interventions from pharmaceutical to environmental, complicates the task of isolating AI's direct impact on cost-effectiveness. It is challenging, for example, to differentiate the cost benefits of an AI-driven early warning system from simultaneous environmental interventions in a patient's residence. The initial investments for AI, encompassing infrastructure to training, might deter immediate evaluations, especially when weighed against potential long-term benefits. The swiftly evolving nature of AI technologies adds another layer of complexity. An algorithm deemed cutting-edge today might become obsolete in a few years, making its cost-effectiveness evaluation intricate. Ethical dilemmas, especially concerning data privacy, further muddy the waters. While an AI system might adeptly predict asthma exacerbations using patient data, apprehensions about data security and patient consent can hinder its broad adoption and subsequent cost assessment. Additionally, the inherent variability in healthcare systems worldwide introduces challenges; a cost-effectiveness model in one country might not be directly applicable in another, such as the UK's National Health Service.

Financial burden associated with asthma care can vary widely, from medication costs and emergency department (ED) visits, to admission costs for hospitalizations. Study data offers insight into these costs; for instance, an expenditure related to emergency department visits was estimated as representing between 7 and 18% of direct costs; hospitalization during such visits cost an average of $3,102.53 per patient incurred and 10.4% was allocated toward medication costs[17]. On a larger scale, these individual costs add up to an enormous economic burden, with asthma accounting for more than 439,000 hospitalizations and 1.7 million emergency department visits every year in the US alone, costing approximately $50 billion in healthcare expenditure[17].

Both cost reduction and medication adherence have consistently been focal points of health policy dialogues. AI technology presents encouraging prospects for enhancing medication adherence, which can markedly reduce emergency care and hospitalization expenses. Smart inhalers epitomize this potential. Incorporating sensors and Bluetooth technology, these devices can monitor medication use, remind patients about adherence, and furnish healthcare providers with pertinent data for improved disease management[18].

Nevertheless, the potential economic benefits of ML in healthcare are starting to surface in other domains. Studies assessing ML's economic feasibility in conditions like melanoma and diabetic retinopathy have yielded mixed outcomes. One study posited that enhanced diagnostic capabilities don't invariably equate to cost-effectiveness[19], while another deduced that universal screening for ALVD using AI-ECG is cost-effective in most clinical scenarios, with costs under $50,000 per quality-adjusted life year (QALY)[20].

While there is a lack of empirical data, ML holds the potential to offer significant economic benefits in asthma care. Misdiagnoses or late detections of asthma can lead to unnecessary treatments and hospital visits, which ML can potentially mitigate. By analyzing extensive datasets, such as electronic health records and prescription histories, ML can pinpoint early indicators of asthma that might be overlooked by clinicians, paving the way for timely interventions and reducing emergency care costs.

Given asthma's inherent complexity, where a treatment effective for one patient might not be for another, there's a growing need for personalized care. ML can address this by analyzing individual patient data to predict responses to various treatments. This tailored approach reduces the reliance on trial-and-error, hastening patient recovery and optimizing healthcare expenditure. For instance, an ML model might forecast a patient's responsiveness to a specific medication combination based on factors like genetics, environmental exposures, and medical history.

In the realm of patient monitoring, AI promises notable economic advantages. Traditional methods often respond to reported symptoms, whereas AI enables proactive monitoring. Wearable devices, equipped with sensors that gather real-time data on respiratory patterns and vital signs, combined with ML analysis, can anticipate potential asthma attacks early, facilitating timely interventions and potentially reducing the costs associated with severe exacerbations.

From an administrative perspective, ML can enhance resource allocation in healthcare settings. For example, during high-risk periods like pollen seasons, when asthma cases are expected to surge, ML can help healthcare facilities anticipate and prepare for this increased demand, ensuring adequate medication stocks and efficient staff deployment, thereby enhancing patient care and optimizing costs.

Cost of AI

Financial considerations associated with integrating Artificial Intelligence (AI) into healthcare can extend across various domains. The inclusion of AI into settings such as the National Health Service (NHS) demands a comprehensive analysis of both immediate investment needs and expected long-term economic benefits. Estimates suggest that healthcare expenditures could decrease by 5–10%, resulting in annual savings ranging from $200 billion to $360 billion, all while maintaining high-quality healthcare services[21]. Concurrently, AI-driven solutions might yield immediate fiscal benefits through cost savings, innovation augmentation, and enhanced consumer engagement. Initially, the costs of investing in AI technology, encompassing hardware, software, and data infrastructure, may appear prohibitively high. Moreover, establishing an efficient data governance and security framework is essential for the successful integration of AI.

The cost dynamics associated with healthcare innovation through Artificial Intelligence (AI) are complex and multidimensional. AI holds great promise for improving patient diagnoses, prevention, treatment practices, and overall cost-efficiency; however, historical data often demonstrates an upward trend in healthcare costs due to innovation[22]. One of the many touted advantages of AI in healthcare is its potential to streamline existing healthcare processes while creating more efficient ones, thereby helping to reduce healthcare costs globally[22]. One literature review even suggests that adopting AI could cut annual US healthcare expenses by USD 150 billion by 2026, although no quantitative data exists due to AI's recent introduction[23]. However, the user expresses valid concerns over AI diagnostics being more widely implemented, which could incur additional costs. This fear stems from AI systems having the potential to generate false positives during diagnostic procedures that lead to unnecessary treatments, escalating healthcare costs further. Furthermore, initial investment costs, along with ongoing updates and maintenance, could add another financial burden; additionally, interoperability issues between AI systems may pose additional financial hurdles that need overcoming before implementation can even take place.

Discussion around whether Artificial Intelligence will follow historical trends of innovation leading to higher costs or reverse them by decreasing them has long been ongoing. The real effects of AI on healthcare costs will likely depend on various factors including its level of integration, the accuracy and efficiency of the systems used, as well as the adaptability of larger healthcare ecosystems to this technological innovation.

Conclusion

The integration of AI, particularly ML into asthma care is well-documented and holds significant promise. However, empirical studies examining its economic implications are still limited. Despite this, ML's capabilities, ranging from early diagnosis and personalized treatment to proactive monitoring, suggest potential benefits for both patient outcomes and economic efficiency. As the field continues to evolve, further research will undoubtedly provide a deeper understanding of AI's holistic impact on asthma management, both clinically and economically.

Transparency

Declaration of funding

The paper was not funded.

Declaration of financial/other relationships

The author has no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.

Author contributions

AZA developed the study design, performed data extraction, manuscript drafting, and reviewing.

Acknowledgements

None stated.

Reviewer disclosures

Peer reviewers on this manuscript have no relevant financial or other relationships to disclose.

ORCID

Ahmad Z. Al Meslamani http://orcid.org/0000-0002-8370-9562

References

[1] WHO. Chronic respiratory diseases: asthma; 2021. Available from: https://www.who.int/news-room/questions-and-answers/item/chronic-respiratory-diseases-asthma

[2] Nurmagambetov T, Kuwahara R, Garbe P. The economic burden of asthma in the United States, 2008-2013. Ann Am Thorac Soc. 2018;15(3):348–356. doi: 10.1513/AnnalsATS.201703-259OC.

[3] Costa E, Caetano R, Werneck GL, et al. Estimated cost of asthma in outpatient treatment: a real-world study. Rev Saude Publica. 2018;52:27. doi: 10.11606/S1518-8787.2018052000153.

[4] Exarchos KP, Beltsiou M, Votti C-A, et al. Artificial intelligence techniques in asthma: a systematic review and critical appraisal of the existing literature. Eur Respir J. 2020;56(3):2000521. doi: 10.1183/13993003.00521-2020.

[5] Al Meslamani AZ. Applications of AI in pharmacy practice: a look at hospital and community settings. J Med Econ. 2023;26(1):1081–1084. doi: 10.1080/13696998.2023.2249758.

[6] Xiong S, Chen W, Jia X, et al. Machine learning for prediction of asthma exacerbations among asthmatic patients: a systematic review and meta-analysis. BMC Pulm Med. 2023;23(1):278. doi: 10.1186/s12890-023-02570-w.

[7] Zein JG, Wu C-P, Attaway AH, et al. Novel machine learning can predict acute asthma exacerbation. Chest. 2021;159(5):1747–1757. doi: 10.1016/j.chest.2020.12.051.

[8] López-Tiro J, Contreras-Contreras A, Rodríguez-Arellano ME, et al. Economic burden of severe asthma treatment: a real-life study. World Allergy Organ J. 2022;15(7):100662. doi: 10.1016/j.waojou.2022.100662.

[9] McCradden MD, Joshi S, Mazwi M, et al. Ethical limitations of algorithmic fairness solutions in health care machine learning. Lancet Digit Health. 2020;2(5):e221–e223. doi: 10.1016/S2589-7500(20)30065-0.

[10] Thomasian NM, Eickhoff C, Adashi EY. Advancing health equity with artificial intelligence. J Public Health Policy. 2021;42(4):602–611. doi: 10.1057/s41271-021-00319-5.

[11] Martin C, DeStefano K, Haran H, et al. The ethical considerations including inclusion and biases, data protection, and proper implementation among AI in radiology and potential implications. Intell. Med. 2022;6:100073. doi: 10.1016/j.ibmed.2022.100073.

[12] Ekpo RH, Osamor VC, Azeta AA, et al. Machine learning classification approach for asthma prediction models in children. Health Technol. 2023;13(1):1–10. doi: 10.1007/s12553-023-00732-8.

[13] Yu G, Li Z, Li S, et al. The role of artificial intelligence in identifying asthma in pediatric inpatient setting. Ann Transl Med. 2020;8(21):1367–1367. doi: 10.21037/atm-20-2501a.

[14] Haba R, Singer G, Naftali S, et al. A remote and personalised novel approach for monitoring asthma severity levels from EEG signals utilizing classification algorithms. Expert Syst. Appl. 2023;223:119799. doi: 10.1016/j.eswa.2023.119799.

[15] Ray A, Das J, Wenzel SE. Determining asthma endotypes and outcomes: complementing existing clinical practice with modern machine learning. Cell Rep Med. 2022;3(12):100857. doi: 10.1016/j.xcrm.2022.100857.

[16] Howard R, Rattray M, Prosperi M, et al. Distinguishing asthma phenotypes using machine learning approaches. Curr Allergy Asthma Rep. 2015;15(7):38. doi: 10.1007/s11882-015-0542-0.

[17] Stanford R, McLaughlin T, Okamoto LJ. The cost of asthma in the emergency department and hospital. Am J Respir Crit Care Med. 1999;160(1):211–215. doi: 10.1164/ajrccm.160.1.9811040.

[18] van de Hei SJ, Poot CC, van den Berg LN, et al. Effectiveness, usability and acceptability of a smart inhaler programme in patients with asthma: protocol of the multicentre, pragmatic, open-label, cluster randomised controlled ACCEPTANCE trial. BMJ Open Respir Res. 2022;9(1):65–71. doi: 10.1136/bmjresp-2022-001400.
[19] Gomez Rossi J, Rojas-Perilla N, Krois J, et al. Cost-effectiveness of artificial intelligence as a decision-support system applied to the detection and grading of melanoma, dental caries, and diabetic retinopathy. JAMA Netw Open. 2022;5(3):e220269. doi: 10.1001/jamanetworkopen.2022.0269.
[20] Tseng AS, Thao V, Borah BJ, et al. Cost effectiveness of an electrocardiographic deep learning algorithm to detect asymptomatic left ventricular dysfunction. Mayo Clin Proc. 2021;96(7):1835–1844. doi: 10.1016/j.mayocp.2020.11.032.
[21] Sahni NR. The potential impact of artificial intelligence on healthcare spending; 2023. Available from: https://www.nber.org/system/files/chapters/c14760/c14760.pdf#:~:text=AIadoptioninhealthcarecould,otherindustriesinAIadoption
[22] Zahlan A, Ranjan RP, Hayes D. Artificial intelligence innovation in healthcare: literature review, exploratory analysis, and future research. Technol Soc. 2023;74:102321. doi: 10.1016/j.techsoc.2023.102321.
[23] Ali O, Abdelbaki W, Shrestha A, et al. A systematic literature review of artificial intelligence in the healthcare sector: benefits, challenges, methodologies, and functionalities. J Innov Knowl. 2023;8(1):100333. doi: 10.1016/j.jik.2023.100333.