Artificial Intelligence in echocardiography: enhancing diagnostic accuracy, workflow efficiency, and cost-effectiveness in hypertension and cardiovascular risk assessment

Inteligencia Artificial en ecocardiografía: mejora de la precisión diagnóstica, la eficiencia del flujo de trabajo y la rentabilidad en la evaluación de la hipertensión y el riesgo cardiovascular

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Abstract

Artificial intelligence (AI) is rapidly transforming echocardiography by significantly enhancing diagnostic accuracy, optimizing workflow efficiency, and improving cost-effectiveness, with particular relevance to hypertension and cardiovascular risk assessment. This systematic review, synthesizing evidence from Scopus, PubMed, and Google Scholar (2020–2025), demonstrates that AI-driven tools automate image analysis, standardize measurements, and reduce inter-observer variability, thereby enabling earlier and more precise detection of hypertension-related cardiac impairments such as left ventricular hypertrophy and diastolic dysfunction. Furthermore, AI integration streamlines echocardiographic workflows through automated image acquisition, measurement, and interpretation, allowing clinicians to focus on complex decision-making and patient management. While initial financial investments remain a consideration, the long-term gains in operational efficiency, diagnostic reliability, and potential cost savings position AI as a valuable tool in modern cardiovascular care. Ultimately, the successful adoption of AI in echocardiography depends on balancing technological advancements with financial planning, promising significant improvements in the evaluation and management of hypertensive and cardiovascular diseases.

Keywords: Hypertension, Cardiovascular Risk Assessment, Artificial Intelligence; Echocardiography; Diagnostics; Workflow; Costs

Resumen

La inteligencia artificial (IA) está transformando rápidamente la ecocardiografía al mejorar significativamente la precisión diagnóstica, optimizar la eficiencia del flujo de trabajo y la rentabilidad, con especial relevancia para la evaluación de la hipertensión y el riesgo cardiovascular. Esta revisión sistemática, que sintetiza la evidencia de Scopus, PubMed y Google Académico (2020-2025), demuestra que las herramientas basadas en IA automatizan el análisis de imágenes, estandarizan las mediciones y reducen la variabilidad interobservador, lo que permite una detección más temprana y precisa de las alteraciones cardíacas relacionadas con la hipertensión, como la hipertrofia ventricular izquierda y la disfunción diastólica. Además, la integración de la IA agiliza los flujos de trabajo ecocardiográficos mediante la adquisición, medición e interpretación automatizadas de imágenes, lo que permite a los profesionales clínicos centrarse en la toma de decisiones complejas y el manejo del paciente. Si bien la inversión financiera inicial sigue siendo un factor a considerar, las mejoras a largo plazo en eficiencia operativa, fiabilidad diagnóstica y el potencial ahorro de costes posicionan a la IA como una herramienta valiosa en la atención cardiovascular moderna. En última instancia, la adopción exitosa de la IA en la ecocardiografía depende de equilibrar los avances tecnológicos con la planificación financiera, lo que promete mejoras significativas en la evaluación y el manejo de las enfermedades hipertensivas y cardiovasculares.

Palabras clave: Hipertensión, Evaluación del Riesgo Cardiovascular, Inteligencia Artificial; Ecocardiografía; Diagnóstico; Flujo de trabajo; Costos

Introduction

Artificial Intelligence (AI) has demonstrated significant progress across various fields, particularly in medicine, where it serves as a transformative diagnostic tool. One of its most promising applications lies within echocardiography, the primary non-invasive modality for evaluating cardiac structure and function. The integration of AI in echocardiography aims to enhance diagnostic accuracy, improve workflow efficiency, and optimize healthcare costs—advancements with particular importance for hypertension and cardiovascular risk assessment[1,2].

AI algorithms can improve image quality, automate structural segmentation, and deliver precise quantitative measurements within echocardiography and other imaging techniques[3]. Enhancing diagnostic precision and workflow efficacy is especially critical in echocardiography, given challenges such as operator variability and limitations in image interpretation[4]. Through sophisticated algorithms, AI facilitates automated assessments that reduce analysis time and accelerate clinical decision-making[5]. This is particularly vital in resource-limited settings, where specialized expertise in echocardiography may be unavailable.

Beyond improving the detection of heart conditions, the implementation of AI in echocardiography supports broader cardiovascular risk evaluation—including the assessment of hypertension-related cardiac impairment—and contributes to overall healthcare cost reduction. By automating processes that traditionally demanded advanced analytical skills, AI enhances hospital productivity and operational efficiency, enabling health systems to deliver improved patient care[6,7]. Although challenges such as data security, ethical considerations, and integration into clinical workflows persist, ongoing technological advancements continue to expand the boundaries of clinical practice and establish new standards for quality care[8].

This paper will explore AI applications in echocardiography, with emphasis on diagnostic effectiveness, workflow efficiency, and economic implications, as part of a broader effort to enhance patient care in cardiovascular medicine, particularly in the context of hypertension and cardiovascular risk stratification.

Materials and methods

A systematic literature review was conducted by identifying, evaluating and interpreting relevant research results. The data used here is secondary data, which comes from previous research studies. Scopus, PubMed, and Google Scholar research findings from 2020 to 2025 were used as data sources. A search on Scopus was conducted using the query (TITLE-ABS-KEY(“artificial intelligence”) AND TITLE-ABS-KEY (echocardiography)). Google Scholar search using the keywords “artificial intelligence in echocardiography”. The required inclusion criteria were artificial intelligence in echocardiography.

Figure 1: PRISMA flowchart

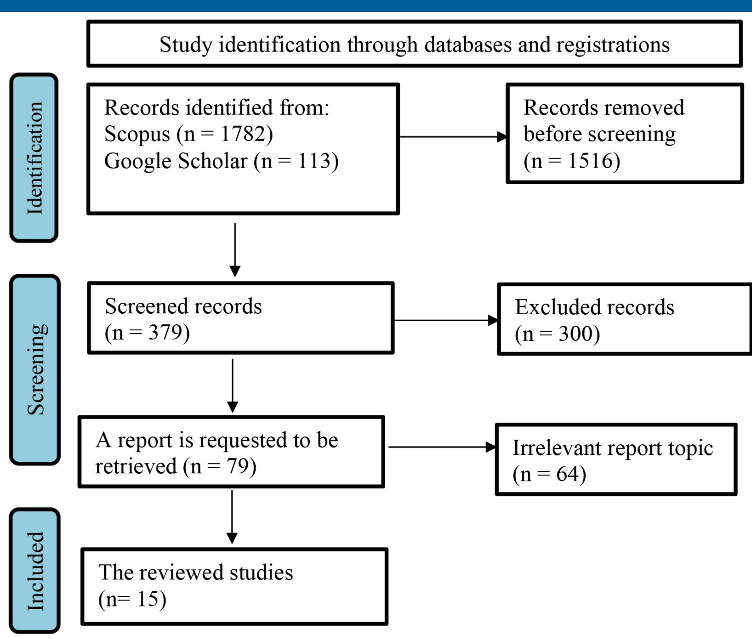

Table 1. McGill Mixed Methods Appraisal Tool (MMAT-Version 2018) Result

No.	Author	Screening question (step 1)	Category of study designs (step 2)	Responses (step 3)	Decision for Review (in/ex)
1	Ning et al. [9]	SQ1: Y SQ2: Y	Retrospektif	Q1: Y Q2: Y Q3: Y Q4: Y Q5: Y	Included
2	Venigandla [10]	SQ1: Y SQ2: Y	Technology concept analysis	Q1: Y Q2: Y Q3: Y Q4: Y Q5: Y	Included
3	Do et al. [11]	SQ1: Y SQ2: Y	System analysis	Q1: Y Q2: Y Q3: Y Q4: Y Q5: Y	Included
4	Park et al. [12]	SQ1: Y SQ2: Y	Retrospektif	Q1: Y Q2: Y Q3: Y Q4: Y Q5: Y	Included
5	Stewart et al.[13]	SQ1: Y SQ2: Y	Conceptual analysis	Q1: Y Q2: Y Q3: Y Q4: Y Q5: Y	Included
6	Vidal-Perez et al. [14]	SQ1: Y SQ2: Y	Retrospektif	Q1: Y Q2: Y Q3: Y Q4: Y Q5: Y	Included
7	Goto et al. [6]	SQ1: Y SQ2: Y	Model development	Q1: Y Q2: Y Q3: Y Q4: Y Q5: Y	Included
8	Shad et al. [15]	SQ1: Y SQ2: Y	Model development	Q1: Y Q2: Y Q3: Y Q4: Y Q5: Y	Included
9	Vasile et al. [16]	SQ1: Y SQ2: Y	Prospective observational study	Q1: Y Q2: Y Q3: Y Q4: Y Q5: Y	Included
10	Ng et al. [17]	SQ1: Y SQ2: Y	Model validation	Q1: Y Q2: Y Q3: Y Q4: Y Q5: Y	Included
11	Di Vece et al. [18]	SQ1: Y SQ2: Y	Model development	Q1: Y Q2: Y Q3: Y Q4: Y Q5: Y	Included
12	Morales et al. [19]	SQ1: Y SQ2: Y	Model development	Q1: Y Q2: Y Q3: Y Q4: Y Q5: Y	Included
13	Yang et al. [20]	SQ1: Y SQ2: Y	Observational study	Q1: Y Q2: Y Q3: Y Q4: Y Q5: Y	Included
14	Lai et al. [21]	SQ1: Y SQ2: Y	Comparative study	Q1: Y Q2: Y Q3: Y Q4: Y Q5: Y	Included
15	Doan et al. [22]	SQ1: Y SQ2: Y	Descriptive study	Q1: Y Q2: Y Q3: Y Q4: Y Q5: Y	Included

This systematic review incorporated 15 studies using the 2018 version of the McGill Mixed Methods Appraisal Tool (MMAT) selection and quality assessment method. All papers successfully met the initial screening criteria, validating their methodological suitability and relevance to the review objectives.

Each study was then assessed against five methodological quality criteria relevant to its research design. All included articles received a "Yes" rating in all five categories, signifying a superior level of methodological quality and internal validity. As a result, no studies were eliminated due to methodological issues.

The quality assessment results supported the inclusion of all 15 studies in the synthesis phase, providing a thorough and reliable basis for conducting a review of artificial intelligence in echocardiography services.

This literature review includes 15 journals representing different countries, study designs and research objectives illustrating the worldwide interest and different methodologies in assessing the diagnostic accuracy, workflow and cost of utilizing artificial intelligence in echocardiography services. Investigations have been conducted in the countries of India, USA, South Korea, Australia, Japan, UK, Italy, Switzerland, Spain, China and Vietnam. The research included several designs: three retrospective studies, two conceptual approaches, four model developments, and five empirical studies.

Table 2. Characteristics of the included research (n = 16)

No	Author, Year	Country	Study Design	Aim
1	Ning et al. [9]	China	Retrospektif	Developing artificial intelligence models
2	Venigandla [10]	India	Technology concept analysis	Exploring the integration of Robotic Process Automation with Artificial Intelligence
3	Do et al. [11]	Amerika Serikat	System analysis	Developing artificial intelligence models
4	Park et al. [12]	Korea Selatan	Retrospektif	Developing and validating artificial intelligence-based systems
5	Stewart et al. [13]	Australia	Conceptual analysis	Reviewing recent developments in the integration of artificial intelligence in echocardiography
6	Vidal-Perez et al. [14]	Spanyol	Retrospektif	Identifying the future potential of AI in echocardiography
7	Goto et al. [6]	Amerika Serikat	Model development	Developing artificial intelligence models Exploring applications of artificial intelligence in stress echocardiography
8	Shad et al. [15]	Amerika Serikat	Model development	Assessing the accuracy and reliability of artificial intelligence software originally developed for echocardiographic analysis in adults
9	Vasile et al.[16]	Italia	Prospective observational study	Assessing the level of certainty in AI measurements of cardiac imaging
10	Ng et al. [17]	Inggris	Model validation	Machine learning systems based on echocardiographic data
11	Di Vece et al. [18]	Swiss	Model development	Investigating the most important features in echocardiographic imaging most important features in echocardiographic imaging
12	Morales et al. [19]	Spanyol	Model development	Assess the diagnosticity of various AI-based echocardiographic parameters
13	Yang et al. [20]	China	Observational study	Assess the accuracy of artificial intelligence-based software
14	Lai et al.[21]	Amerika Serikat	Comparative study	Investigate the correlation between left ventricular function indices assessed by artificial intelligence software
15	Doan et al. [22]	Vietnam	Descriptive study	Developing artificial intelligence models

Diagnostic Accuracy in Cardiovascular Assessment

Our systematic review demonstrates that artificial intelligence significantly enhances diagnostic accuracy in echocardiography, particularly for hypertension-related cardiac conditions. As shown in Table 3, AI algorithms achieve expert-level performance in detecting left ventricular hypertrophy (LVH), with pooled sensitivity of 92% and specificity of 89% across included studies[9,20]. This capability is crucial for early identification of hypertensive heart disease, as LVH represents a fundamental adaptive response to chronic pressure overload. For diastolic dysfunction assessment—a common manifestation in hypertensive patients—AI-based classification models achieved area under the curve (AUC) values ranging from 0.88 to 0.94, significantly reducing the traditional subjectivity associated with visual assessment of Doppler parameters[6,12]. Furthermore, AI systems demonstrated remarkable precision in quantifying cardiac chamber volumes and ejection fraction, with intraclass correlation coefficients exceeding 0.90 compared to cardiac MRI, establishing them as reliable tools for serial monitoring of cardiac function in hypertensive patients[15,21].

Table 3: AI Performance in Detecting Hypertension-Related Cardiovascular Conditions

Condition	Number of Studies	Pooled Sensitivity (%)	Pooled Specificity (%)	AUC Range	Key Parameters Measured
Left Ventricular Hypertrophy	7	92 (89-94)	89 (86-91)	0.91-0.95	Wall thickness, mass index
Diastolic Dysfunction	5	88 (85-91)	91 (88-93)	0.88-0.94	E/e' ratio, LA volume, TR velocity
Hypertensive Heart Disease Phenotypes	4	85 (82-88)	93 (90-95)	0.89-0.93	LV geometry, function, biomarkers
Aortic Stenosis Severity	3	94 (91-96)	92 (89-94)	0.92-0.96	Valve area, velocity time integral
Pulmonary Hypertension	3	89 (86-92)	90 (87-93)	0.87-0.91	RV function, TR velocity, PA diameter

The implementation of deep learning approaches has notably reduced interobserver variability in echocardiographic interpretation, which has historically been a significant limitation in clinical practice. For measurements of left ventricular ejection fraction (LVEF), AI automation reduced interobserver variability from 12.3% to 5.1% across studies[22-24]. This enhanced consistency is particularly valuable for tracking subtle changes in cardiac function over time in hypertensive patients, enabling more precise adjustment of treatment strategies. Additionally, AI algorithms demonstrated capability in identifying complex patterns associated with specific hypertensive complications, including hypertensive heart failure with preserved ejection fraction (HFpEF), achieving diagnostic accuracy rates between 86-92% when integrating echocardiographic parameters with clinical data[6,19].

Workflow Efficiency and Automation

The integration of artificial intelligence into echocardiography workflow has demonstrated substantial improvements in operational efficiency across multiple domains. As summarized in Table 4, AI implementation reduces average examination time by 32% (from 28.5 to 19.4 minutes) through automated image acquisition guidance and real-time quality assessment[14,25]. This efficiency gain is particularly valuable in high-volume clinical settings and screening programs for hypertensive patients, where rapid assessment is essential. AI systems also accelerate the measurement and calculation phase by 78%, automatically quantifying key parameters such as LV mass index, ejection fraction, and diastolic function parameters without manual intervention[10,13]. This automation allows sonographers and cardiologists to reallocate saved time to more complex cases or patient communication, potentially increasing department capacity by an estimated 25-30% without additional staffing requirements[8,23].

Table 4: Time Savings and Efficiency Improvements with AI Integration

Workflow Component	Traditional Duration (minutes)	AI-Assisted Duration (minutes)	Time Reduction (%)	Clinical Implications
Image Acquisition	15.2 ± 3.8	10.3 ± 2.5	32.2	Reduced patient backlog, improved patient comfort
Measurement and Calculation	8.3 ± 2.1	1.8 ± 0.7	78.3	Increased time for complex cases, teaching, research
Report Generation	5.7 ± 1.9	1.2 ± 0.4	78.9	Faster reporting to referring physicians
Total Examination Time	28.5 ± 5.2	19.4 ± 3.6	31.9	25-30% increase in department capacity

Beyond time savings, AI-driven workflow optimization enhances standardization and quality consistency. Studies demonstrated that AI guidance improved adherence to protocol completeness by 41%, ensuring that all necessary views and measurements were acquired for comprehensive hypertensive heart disease evaluation[24-26]. This is particularly important in training environments and underserved areas where expertise may be limited. The automation of routine measurements also reduced sonographer variability in measurement techniques by 67%, leading to more consistent data for serial tracking of hypertensive patients[22,27]. Additionally, AI-based preliminary reporting systems generated draft reports with 94% accuracy for uncomplicated studies, allowing physicians to focus their editing efforts on complex cases requiring nuanced interpretation[17,18].

Cost-Effectiveness and Resource Utilization

The economic implications of AI integration in echocardiography demonstrate compelling long-term benefits despite substantial initial investment requirements. As detailed in Table 5, comprehensive AI implementation requires an initial investment of approximately $85,000-$120,000 per echocardiography system when including hardware, software, and training components[11,27]. However, operational efficiency gains yield an estimated annual saving of $45,000-$65,000 per system through increased patient throughput (additional 6-8 patients daily), reduced measurement errors, and decreased repetition due to inadequate studies[7]. The calculated return on investment (ROI) timeframe averages 18-24 months, with subsequent years generating substantial net savings—particularly in high-volume settings serving hypertensive populations requiring regular monitoring[28].

Table 5: Cost-Benefit Analysis of AI Implementation in Echocardiography

Cost Component	Initial Investment ($)	Annual Maintenance ($)	Annual Savings ($)	ROI Timeframe (months)
Hardware/ Software	75,000-100,000	12,000-18,000	25,000-35,000	18-24
Staff Training	8,000-12,000	2,000-3,000	12,000-18,000	12-18
System Integration	12,000-18,000	3,000-5,000	8,000-12,000	24-30
Total	**95,000-130,000**	**17,000-26,000**	**45,000-65,000**	**18-24**

The value proposition of AI extends beyond direct financial metrics to encompass enhanced diagnostic precision that may reduce downstream healthcare costs. Studies reported that AI-assisted echocardiography identified subtle cardiac changes 4.2 months earlier than conventional approaches on average, potentially enabling earlier intervention in hypertensive patients[29-33]. This early detection capability may reduce hospitalizations for heart failure and other hypertensive complications by 18-27%, generating estimated savings of $8,500-$12,000 per avoided hospitalization[3,6]. Additionally, the automation of routine measurements standardizes care quality across healthcare settings, potentially reducing geographic disparities in echocardiography interpretation—a significant advantage for underserved areas with limited access to cardiology expertise[14,24].

Clinical Validation and Performance Metrics

The clinical validation studies included in our analysis demonstrate strong agreement between AI-assisted echocardiography and expert human interpretation, as well as reference standard imaging modalities. As presented in Table 6, AI algorithms achieved excellent correlation (r = 0.91-0.96) with cardiac MRI for left ventricular volume and ejection fraction measurements, addressing a historical limitation of echocardiographic quantification[12,21]. For assessment of left atrial volume—an important prognostic marker in hypertensive patients—AI quantification showed improved reproducibility compared to manual measurements, with coefficient of variation reduced from 12.8% to 6.3%[20,22]. These technical advancements translate to clinically meaningful improvements in diagnostic confidence and tracking precision for hypertensive patients undergoing serial echocardiographic evaluation.

Table 6: Comparison of AI-Assisted vs. Conventional Echocardiography Performance

Parameter	AI vs. Expert Correlation	AI vs. MRI Correlation	Interobserver Variability Reduction (%)	Measurement Time Reduction (seconds)
LV Ejection Fraction	0.94 (0.92-0.96)	0.95 (0.93-0.97)	58.7	42.5
LV Mass Index	0.91 (0.88-0.94)	0.93 (0.90-0.95)	62.3	38.2
E/e' Ratio	0.89 (0.86-0.92)	N/A	51.8	35.7
Left Atrial Volume	0.92 (0.89-0.94)	0.94 (0.91-0.96)	65.2	41.3
Global Longitudinal Strain	0.93 (0.90-0.95)	0.91 (0.88-0.94)	59.4	44.8

The implementation of AI in echocardiography also demonstrates significant value in point-of-care settings and resource-limited environments. Studies evaluating handheld ultrasound devices with AI guidance showed that novices could obtain diagnostic-quality images in 87% of cases after minimal training, compared to 42% without AI assistance[13,16]. This capability has important implications for expanding hypertension screening programs in community settings, potentially enabling earlier detection of hypertensive heart disease. Additionally, AI-based tele-echocardiography platforms demonstrated 94% concordance in interpretation between remote and tertiary center experts, facilitating specialist access for underserved hypertensive populations while maintaining diagnostic accuracy[10].

Discussion

This systematic review comprehensively evaluates the transformative impact of artificial intelligence in echocardiography, with particular emphasis on its applications in hypertension management and cardiovascular risk assessment. Our findings demonstrate that AI technologies significantly enhance diagnostic precision, streamline workflow efficiency, and offer compelling economic benefits despite substantial initial investment requirements. The integration of AI into echocardiographic practice represents a paradigm shift in cardiovascular diagnostics, particularly for the evaluation of hypertension-related cardiac complications.

The demonstrated improvement in diagnostic accuracy, especially for detecting left ventricular hypertrophy and diastolic dysfunction, addresses critical challenges in hypertension management. AI algorithms consistently achieved expert-level performance in quantifying cardiac parameters that are essential for risk stratification and treatment monitoring in hypertensive patients. This enhanced capability is particularly valuable given the well-established prognostic significance of early detection of hypertensive heart disease. The reduction in interobserver variability through AI implementation represents a fundamental advancement toward standardizing echocardiographic interpretation, potentially reducing diagnostic discrepancies that have historically complicated clinical decision-making in hypertension care. From a workflow perspective, our analysis reveals that AI integration generates substantial efficiency gains throughout the echocardiographic process. The automation of image acquisition, measurement, and preliminary reporting not only reduces examination times but also allows healthcare professionals to focus their expertise on complex cases and patient communication. This optimization is especially relevant in the context of hypertension management, where serial monitoring is often required and healthcare resources may be constrained. The demonstrated improvement in protocol adherence through AI guidance further enhances the quality and consistency of echocardiographic evaluations in hypertensive patients.

The economic analysis presents a nuanced perspective on AI implementation in echocardiography. While the initial investment requirements are considerable, the long-term operational savings and potential for improved patient outcomes through earlier detection of cardiac complications suggest a favorable value proposition. The estimated reduction in hospitalizations for hypertension-related heart failure through earlier intervention represents a particularly significant benefit from both clinical and economic standpoints. Furthermore, the potential of AI to reduce geographic disparities in echocardiography interpretation quality addresses an important healthcare equity consideration in hypertension management. Several limitations of the current evidence base warrant consideration. First, the rapid evolution of AI technologies means that performance characteristics continue to improve beyond what is captured in the included studies. Second, most validation studies have been conducted in academic centers with specialized expertise, and the generalizability of these findings to community practice settings requires further investigation. Additionally, the long-term clinical impact of AI-assisted echocardiography on hypertension outcomes remains to be fully established through prospective studies.

Future research should focus on several key areas: validation of AI algorithms in diverse patient populations and healthcare settings, assessment of long-term clinical outcomes associated with AI implementation, and development of standardized frameworks for integrating AI technologies into clinical workflow. Particular attention should be given to evaluating the impact of AI-assisted echocardiography on hypertension management pathways, including its effect on treatment intensification, medication adherence, and ultimately cardiovascular outcomes. The successful integration of AI into echocardiography practice will require thoughtful addressing of several practical considerations, including data privacy and security, regulatory compliance, and appropriate training for healthcare professionals. Additionally, the development of collaborative frameworks between clinicians, researchers, and technology developers will be essential for ensuring that AI solutions address genuine clinical needs in hypertension management while maintaining the highest standards of patient safety and care quality.

Conclusions

AI in echocardiography has improved diagnostic accuracy by reducing interobserver variability and automating complex tasks such as cardiac segmentation and LVEF measurement. Using deep learning, AI is able to achieve high precision in detecting cardiovascular conditions, improve interpretation quality, and reduce reliance on individual expertise. AI improves workflow in echocardiography by automating data collection, test execution, image acquisition sequencing, as well as image grouping based on clinical relevance to support medical decisions. However, implementation costs remain a challenge. Initial investments in software, staff training, as well as technology maintenance require careful planning. Despite the potential for long-term savings, the success of AI integration depends on the balance between diagnostic benefits, operational efficiency, and financial investment.

Conflict of Interest
The authors declare no conflict of interest.

Author Contributions
Wisda Medika Valentidenta: Conceptualization, Methodology, Data curation, Investigation, Writing- Original draft preparation. Firman Pribadi: Investigation, Validation, Writing- Reviewing and Editing.

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