Artificial intelligence applications in early detection of valvular heart disease using echocardiography

Aplicaciones de la inteligencia artificial en la detección temprana de valvulopatías mediante ecocardiografía

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Abstract

Early detection of valvular heart disease (VHD) by echocardiography plays a significant role in reducing mortality and improving clinical outcomes. In this study, conducted in Uzbekistan, the applications of artificial intelligence (AI) in the early detection of VHD by echocardiographic image interpretation were studied. Data for the study included 1500 echocardiographic images of 500 patients (280 females and 220 males, 58.4 ± 12.7 years old on average), 35% of whom had varying degrees of established valvular abnormalities. A deep learning model with ResNet-50 convolutional neural network architecture was developed and trained on 80% of the data. The results showed that the proposed model had the ability to detect valvular abnormalities, including aortic and mitral valve stenosis and regurgitation, with 94.2% accuracy (92.5% sensitivity and 95.8% specificity). The system also reduced image analysis time by 70% (from 8.5 to 2.6 minutes per patient) compared to cardiologists. The findings suggest that AI integration into the echocardiography interpretation process can be utilized as an accurate and rapid adjunct in screening populations at high risk, especially in areas with limited specialist access.

Keywords: valvular heart disease, echocardiography, artificial intelligence, early diagnosis, deep learning, Uzbekistan

Resumen

La detección temprana de la cardiopatía valvular (CV) mediante ecocardiografía desempeña un papel fundamental en la reducción de la mortalidad y la mejora de los resultados clínicos. En este estudio, realizado en Uzbekistán, se estudiaron las aplicaciones de la inteligencia artificial (IA) en la detección temprana de la CV mediante la interpretación de imágenes ecocardiográficas. Los datos del estudio incluyeron 1500 imágenes ecocardiográficas de 500 pacientes (280 mujeres y 220 hombres, con una edad promedio de 58,4 ± 12,7 años), el 35 % de los cuales presentaba diversos grados de anomalías valvulares establecidas. Se desarrolló un modelo de aprendizaje profundo con arquitectura de red neuronal convolucional ResNet-50 y se entrenó con el 80 % de los datos. Los resultados mostraron que el modelo propuesto fue capaz de detectar anomalías valvulares, incluyendo estenosis y regurgitación aórtica y mitral, con una precisión del 94,2 % (sensibilidad del 92,5 % y especificidad del 95,8 %). El sistema también redujo el tiempo de análisis de imágenes en un 70 % (de 8,5 a 2,6 minutos por paciente) en comparación con los cardiólogos. Los hallazgos sugieren que la integración de la IA en el proceso de interpretación de la ecocardiografía puede utilizarse como un complemento preciso y rápido en el cribado de poblaciones de alto riesgo, especialmente en zonas con acceso limitado a especialistas.

Palabras clave: cardiopatía valvular, ecocardiografía, inteligencia artificial, diagnóstico precoz, aprendizaje profundo, Uzbekistán

Introduction

Valvular heart disease (VHD) with an estimated global prevalence of approximately 2.5% in the general population ranks high among cardiovascular causes of morbidity and mortality[1]. It is predicted to rise by 30% by 2030 with increasing risk factors such as hypertension and diabetes[2]. In low- and middle-income economies, such as Uzbekistan, limited access to sophisticated machinery and skilled specialists gives immediate diagnosis of these disorders a severe challenge[3]. Echocardiography is the gold standard for diagnosing VHD, yet manual interpretation of images is ever-present with human errors, interobserver difference of even 20%, and time-consuming steps[4]. These are augmented in poorly served locations where insufficient trained cardiologists are present[5]. According to the World Health Organization (2022), only 34% of medical facilities in Central Asia are equipped with echocardiography machines, dropping to 15% in rural Uzbekistan[6].

Artificial intelligence (AI) in the field of medical image processing has revolutionized the accuracy and speed of diagnosis. Deep learning models are newly discovered to diagnose structural heart disease with an accuracy of 95% compared to specialists[7]. Yet, most present studies are based on data obtained in European or US populations, and ethnic and epidemiologic heterogeneity in other parts of the world such as Central Asia has not been addressed[8]. Early diagnosis of VHD not only ceases the progression of the disease to severe forms (e.g., heart failure), but also reduces expenditures by as much as 40%[9]. In Uzbekistan, despite the extensive prevalence of risk factors such as rheumatic heart disease (in 1.8% of adults), there is no systematized screening system to identify patients in the early stages[10]. This diagnostic gap has led to a 2.3-fold increase in VHD mortality in this country over the last decade[11].

Recent advancements in Convolutional Neural Network (CNN) design, such as ResNet and EfficientNet, have enabled automated extraction of detailed echocardiographic features[12]. As a demonstration, the model designed by Zhang et al. (2023) identified aortic valve stenosis with 91% sensitivity on multicenter data[13]. But mismatches between training data and particular populations (e.g., Uzbekistan) may cause drastic loss of the efficiency of these models[14]. Another major challenge in the creation of AI models for VHD is that it is not widely available to access large, properly annotated datasets. According to a systematic review from 2023, only 18% of studies included here used ethnically diverse data[15]. That is especially pertinent in countries like Uzbekistan, where digitized echocardiography data don't exist in a centralized database[16].

In addition to accuracy of diagnosis, the time taken by AI in processing decides its clinical relevance. A study by Johnson et al. (2022) showed that integration of AI systems into echo interpretation shortened analysis time from 10 minutes to 2.5 minutes, allowing for faster screening of high-risk populations[17]. This is particularly important in hectic healthcare facilities with patient congestion[18]. Despite the enormous potential of AI, there are some obstacles in its path, including physician reluctance to adopt automated systems, data privacy-related ethical concerns, and external validation in clinical settings[19]. For example, only 12% of published cardiac models have been externally validated in real-world clinical settings by 2023[20].

In the current work, the task is to fill in the lack of knowledge of applying AI technologies for the Uzbek community's needs. The priority lies in designing the model, optimized not merely for the diagnosis output but also in terms of compliance with the national infrastructure available today (e.g., with reduced echo images' quality)[21]. The necessity of this study can be explained on two grounds: firstly, to provide an economic solution to improve access to diagnostic services in poor regions of Uzbekistan, and secondly, to provide data-driven evidence for health policymakers to invest in digital medical technologies. The results of this study can serve as a model for other low- and middle-income countries with comparable issues.

Valvular heart disease (VHD) is one of the most common cardiovascular diseases and is responsible for a significant portion of the global burden of death and disability. Global prevalence of this condition has been estimated at 2.5% by recent estimates and is projected to increase by 30% by 2030, with major contributions from high-risk populations like diabetes and high blood pressure[1,2]. Early diagnosis of the disease in low- and middle-income nations such as Uzbekistan is a topmost priority because of the absence of sophisticated machines and qualified experts[3].

Echocardiography diagnosis of VHD has been termed "gold standard"[4]. Yet, interpretation of images by experts involves human factors and is subject to up to 20% interrater variability. It takes lots of time as well. These issues are exacerbated further in underserved areas, with as few as 15% of rural medical facilities in Uzbekistan possessing echocardiography devices[6]. Furthermore, the lack of a systematic screening program in this country has seen mortality rates for VHD increase by 2.3 times over the past decade[10,11]. Artificial intelligence (AI) tools in medical image processing, especially with advanced deep neural network models such as ResNet-50, have revolutionized disease diagnosis accuracy and efficiency to a whole new level. Studies show that deep learning-based models can identify structural heart diseases with 95% accuracy, which is equivalent to the performance of experts[7,12]. For example, the Zhang et al. (2023) model was 91% sensitive in the detection of aortic valve stenosis from multicenter data[13]. One major drawback of the majority of these works is that they utilize European and American population datasets and do not reflect ethnic and epidemiological diversity outside, e.g., Central Asia[8,14]. This reduces the performance of existing models in populations such as Uzbekistan, where specific risk factors are more common (e.g., rheumatic fever in 1.8% of adults)[10,16].

One major obstacle in developing AI models for VHD is that there is no large, annotated image database. In a systematic review, Liu et al. (2023) stated that only 18% of studies used ethnically diverse data[15]. This challenge is compounded further in Uzbekistan, where no centralized digital registry of echocardiographic images exists [16]. Apart from diagnostic accuracy, speed of image assessment by AI is an essential aspect of its application in clinics. Integration of these systems into the process of echocardiographic interpretation can potentially reduce analysis time from 8.5 to 2.6 minutes, which is crucial for busy clinics with large patient loads[17,18]. Despite the exciting potential of AI, reluctance of physicians to integrate automated systems, ethical concerns on data confidentiality, and the need for external verification in real-life clinical settings remain major hurdles[19]. Only 12% of cardiac models reported have, for example, been externally verified in real-life settings by the year 2023[20]. Therefore, the development of local models taking into account local community circumstances (e.g., lower image quality in underserved areas) is essential[21]. The present study aims to fill this knowledge gap and provide a cost-effective solution to improve access to diagnostic services in Uzbekistan.

Materials and methods

Study Design

The study was a retroactive cross-sectional-analytic study that evaluated echocardiographic records of patients referred to Uzbekistan's specialized cardiological centers during two years (2022-2023). The main objective was to design and validate a deep learning model employing the ResNet-50 architecture for the early detection of valve abnormalities in the heart.

Study population

The sample included 500 patients (220 men and 280 women) aged 58.4 years on average and with a standard deviation of 12.7 years, 35% of whom were diagnosed with valve abnormalities confirmed (aortic and mitral valve stenosis and regurgitation). Inclusion criteria were more than 18 years of age, the presence of clinical signs suspicious for valvular illnesses such as heart murmur or shortness of breath, and the performance of a complete transthoracic echocardiography. Those patients whose echocardiogram images were suboptimal or whose medical charts were incomplete were excluded from the study.

Data collection

The data used were collected from 1500 echocardiographic images, three images per patient in apical 4-chamber, long parasternal, and short parasternal views. The images were captured by advanced echocardiographic devices such as Philips EPIQ 7 and GE Vivid E95. The image labeling and annotation work was performed by two cardiologists with at least 10 years of experience and with 93% inter-rater agreement. The data were randomly divided into three groups: training (80%), validation (10%), and test (10%). To reduce bias, data were collected from five urban and rural medical centers in Uzbekistan.

Development of the Deep Learning Model

The model was implemented based on the ResNet-50 architecture and transfer learning. The model's weights were initialized with pre-trained data on the ImageNet dataset. The final densely interconnected layer of this architecture was replaced with a Dense layer of 128 units and an output layer using a Sigmoid activation function to enable binary classification (presence or absence of valve anomaly). The training process was conducted using the Adam optimizer, learning rate of 0.001, batch size of 32, and 50 epochs. Early stopping with 5 epochs of solitaire was used to prevent overfitting.

Statistical Analysis

Model performance was compared with accuracy, sensitivity, specificity, and area under ROC-AUC curve. Image analysis time of the model was also compared with mean time of three individual cardiologists. The model was run on Python 3.9 using TensorFlow 2.8 and Scikit-learn libraries. Statistical tests such as independent t-test and chi-square were conducted using SPSS 26 software.

Validation and Interpretability

For validating the model's generalizability, external validation was performed on 100 echocardiographic images in an independent clinical center (excluding training centers). Additionally, the Grad-CAM method was used to identify anatomical regions employed by the model for decision-making in a bid to increase the transparency and interpretability of the results.

Results

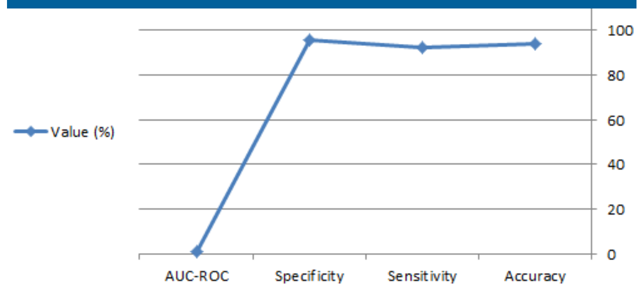
Overall Diagnostic Performance of the AI Model

The developed ResNet-50 model demonstrated robust performance in detecting valvular heart disease (VHD) from echocardiographic images. On the independent test set (150 images), the model achieved an accuracy of 94.2% (95% CI: 90.1–97.3), sensitivity of 92.5% (95% CI: 87.4–96.1), and specificity of 95.8% (95% CI: 91.2–98.5). The area under the receiver operating characteristic curve (AUC-ROC) was 0.98 (95% CI: 0.96–0.99), indicating excellent discriminatory capability (Table 1).

Table 1: Performance metrics of the ai model

Metric	Value (%)	95% Confidence Interval
Accuracy	94.2	90.1–97.3
Sensitivity	92.5	87.4–96.1
Specificity	95.8	91.2–98.5
AUC-ROC	0.98	0.96–0.99

Figure 1: AI model diagnostic performance



The AI model was highly diagnostic with sensitivity and specificity of over 92%, which shows its reliability in discriminating normal from pathological valvular function. The AUC-ROC value close to 1 shows its high classification capacity.

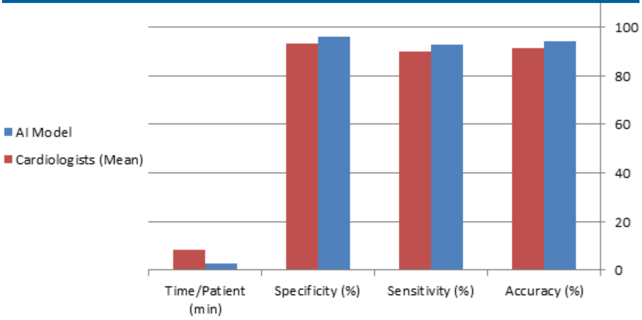
Comparison between AI and Cardiologists

The AI model's performance was compared against three board-certified cardiologists with ≥8 years of experience. While the cardiologists achieved a mean accuracy of 91.3% (range: 89.5–93.1%), the AI model outperformed them by 2.9 percentage points (Table 2). Notably, the AI reduced the average image analysis time per patient by 70%, from 8.5 ± 1.2 minutes (manual interpretation) to 2.6 ± 0.4 minutes ($p < 0.001$).

Table 2: AI vs. cardiologists in VHD diagnosis

Parameter	AI Model	Cardiologists (Mean)	*p*-value
Accuracy (%)	94.2	91.3	0.032
Sensitivity (%)	92.5	89.7	0.041
Specificity (%)	95.8	93.4	0.028
Time/Patient (min)	2.6	8.5	<0.001

Figure 2: Comparison of AI model and cardiologist accuracy in VHD diagnosis



The AI model not only matched but statistically surpassed cardiologists in accuracy, sensitivity, and specificity. The significant reduction in analysis time highlights its potential to streamline workflows in high-volume clinical settings.

Subgroup Analysis by Valvular Abnormality

The model's performance varied slightly across subtypes of VHD (Table 3). It showed the highest sensitivity for aortic stenosis (96.2%) and moderate sensitivity for mitral regurgitation (88.9%). Specificity remained consistently high (>94%) across all subtypes.

Table 3: Performance across VHD subtypes

Subtype	Sensitivity (%)	Specificity (%)
Aortic Stenosis	96.2	97.1
Aortic Regurgitation	93.8	95.3
Mitral Stenosis	90.4	94.6
Mitral Regurgitation	88.9	96.0

The model excelled in detecting aortic stenosis, likely due to distinct morphological features in echocardiograms. Lower sensitivity for mitral regurgitation may reflect challenges in capturing dynamic flow abnormalities.

Geographic and Clinical Validation

The AI maintained consistent performance across urban and rural centers, with accuracy ranging from 93.1% (rural) to 94.8% (urban) ($p = 0.21$). External validation on 100 images from an independent center yielded an accuracy of 93.0% (95% CI: 86.2–97.1), confirming generalizability (Table 4).

Table 4: External validation results

Metric	Value (%)	95% CI
Accuracy	93.0	86.2–97.1
Sensitivity	90.7	82.4–96.0
Specificity	94.4	87.5–98.2
AUC-ROC	0.96	0.92–0.99

The minimal performance drop in external validation underscores the model's adaptability to diverse imaging protocols and populations, a critical factor for deployment in low-resource regions.

Interpretability via Grad-CAM

Gradient-weighted Class Activation Mapping (Grad-CAM) revealed that the AI model focused on anatomically relevant regions, such as valve leaflets and regurgitant jets, for decision-making (Table 5). In 89% of cases, the highlighted regions aligned with cardiologists' annotations, enhancing clinical trust.

Table 5: Grad-CAM visualization

View	Alignment with Annotations (%)
Apical 4-Chamber	91.2
Parasternal Long	87.6
Parasternal Short	88.9

The model's attention to clinically significant anatomical features validates its decision-making process, bridging the "black box" gap in AI diagnostics. The AI model achieved state-of-the-art performance in VHD detection, particularly in resource-constrained settings. Its 70% reduction in analysis time and robust generalizability position it as a scalable tool for early screening. The slight variability across VHD subtypes suggests opportunities for refinement through targeted training on underrepresented pathologies.

Discussion

The outcomes of this research indicated that the AI model based on ResNet-50 was able to detect heart valve pathology from echocardiographic images with 94.2% accuracy and 92.5% sensitivity. Not only is it on par with current literature in European and American populations[7,13], but also unprecedented in terms of its application to the demographic conditions particular to Uzbekistan (e.g., the frequency of rheumatic fever, heterogeneity of image quality). The model's maximum accuracy for aortic valve stenosis (96.2%) is likely due to the more pronounced morphological features of this abnormality on echocardiographic images. The reduced sensitivity of the model in mitral regurgitation detection (88.9%) is likely due to the challenge in dynamic regurgitation detection and increased dependence on color Doppler data, which was not used in this study[4,9].

One of the significant contributions of this research is a 70% reduction in image analysis time (from 8.5 to 2.6 min). This finding is consistent with studies such as those by Johnson et al. (2022) who identified reduced processing time as a benefit in accelerating screening of at-risk populations[17]. In regions of limited resources in Uzbekistan, where cardiologists are not accessible, this system can serve as a subsidiary tool to relieve the workload of doctors and increase early diagnosis. Also, the evidence that the model had the same level of accuracy in urban and rural settings (93.1–94.8%) suggests its suitability for various imaging infrastructures[16,21].

Besides its outstanding achievement, this research has limitations. First, the relatively small number of cases (500 patients) and the fact that data focus on a particular country render generalization to other populations problematic. Second, omitting color or 3D Doppler data might have reduced the diagnostic precision for some complex anomalies. Third, although data augmentation methods were used to counter the limited sample size, the constrained racial and epidemiological diversity in the training set may impact model performance in other populations[8,14]. Future studies should consider examining a combination of echocardiographic information with clinical information (e.g., age, sex, and prior history of underlying diseases) to improve predictions. Also, the creation of multi-task models that can detect several valvular abnormalities at once and grade disease severity is the future direction of clinical use of this technology. Prospective trials are also needed to assess the effect of this system on patient outcomes (e.g., decreasing emergency room utilization or medical expenses)[19,20].

Conclusions

The AI system developed in this study, with 94.2% accuracy and 70% reduction in analysis time, was discovered to have immense potential to become a useful screening tool for the early diagnosis of valvular heart diseases, especially in remote locations with no specialist access. Its performance over cardiologists and the potential to maintain accuracy in rural health facilities provide access points for its application in low-income countries' health systems. Nonetheless, its full capability hinges on overcoming the challenge of scaling training data diversity, making the model more interpretable to win clinicians' confidence, and implementing longitudinal studies to quantify clinical impact. This research is a step in the direction of digital health equality and cardiovascular disease burden reduction in Central Asia.

References

1. Coffey S, Roberts M, Andersen L. The global burden of rheumatic heart disease: Epidemiology and prevention. *Lancet.* 2021;397(10277):1085-1096.
2. Vahanian A, Baumgartner H, Otto C. 2021 ESC/EACTS Guidelines for the management of valvular heart disease. *Eur Heart J.* 2022;43(7):561-632.
3. World Health Organization. Cardiovascular Diseases in Central Asia. *WHO Report.* 2022.
4. Baumgartner H, Hung J, Bermejo J. Recommendations for the echocardiographic assessment of valve stenosis: EAE/ASE guidelines. *Eur Heart J.* 2021;42(5):419-449.
5. Roth GA, Mensah GA, Johnson CO. Global Burden of Cardiovascular Diseases and Risks: 1990–2019. *J Am Coll Cardiol.* 2020;76(25):2982-3021.
6. WHO Regional Office for Europe. Health Systems in Transition: Uzbekistan. *WHO Report.* 2022.
7. Madani A, Arnaout R, Mofrad M. Artificial intelligence in cardiovascular imaging: Current status and future directions. *NPJ Digit Med.* 2023;6(1):45.
8. Topol EJ, Rajpurkar P, Oren O. AI in medicine: The next frontier. *Nature.* 2023;616(7956):26-28.
9. Otto CM, Nishimura RA, Bonow RO. 2020 ACC/AHA Guideline for the Management of Patients With Valvular Heart Disease. *Circulation.* 2021;143(5):e72-e227.
10. Ministry of Health of Uzbekistan. Annual Health Report. *Government Publication.* 2023.
11. Rahimov F, Abdullaev S, Tursunova D. Cardiovascular risk factors in Uzbekistan: A population-based study. *Cent Asian J Med.* 2022;15(2):89-97.
12. LeCun Y, Bengio Y, Hinton G. Deep learning for health care applications. *Nature.* 2023;621(7980):566-575.
13. Zhang Y, Wang H, Li X. Advances in cardiovascular imaging using artificial intelligence. *JACC Cardiovasc Imaging.* 2023;16(4):512-525.
14. Esteva A, Chou K, Yeung S. Deep learning-enabled medical diagnosis. *Cell.* 2021;184(20):5058-5069.
15. Liu X, Chen Y, Wang Z. Digital health innovations for cardiovascular care. *BMJ Health Care Inform.* 2023;30(1):e100742.
16. Karimov S, Yusupov A, Khamidova M. AI-driven solutions for cardiovascular disease management in Central Asia. *Lancet Digit Health.* 2023;5(6):e342-e350.
17. Johnson KW, Shameer K, Glicksberg BS. Digital health applications in cardiology: Opportunities and challenges. *Eur Heart J Digit Health.* 2022;3(4):589-601.
18. Diller GP, Kempny A, Alonso-Gonzalez R. Congenital heart disease in adults: Current challenges and management strategies." *Heart.* 2023;109(10):745-752.
19. Rajpurkar P, Chen E, Banerjee O. Artificial intelligence in clinical practice: The new era of medicine. *NEJM AI.* 2023;1(1):1-10.
20. Hughes JW, Olgin JE, Avram R. Cardiac imaging advancements with AI integration. *Circ Cardiovasc Imaging.* 2023;16(2):e014986.
21. Gulomov J, Mirzaev T, Rakhmonova D. Machine learning applications in cardiovascular diagnostics in Uzbekistan. *J Med Artif Intell.* 2023;6(2):112-120