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Interobserver Agreement in Transthoracic Echocardiography between Cardiology Residents and Attending Cardiologists: A Cross-Sectional Study

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Abstract

Background: Transthoracic echocardiography (TTE) is essential for making clinical decisions regarding cardiovascular disorders. Cardiology trainees frequently conduct and interpret TTE examinations; however, discrepancies between their interpretations and those of attending cardiologists can impact patient management. The objective of this study was to assess the concordance between cardiology trainees and attending cardiologists in the interpretation of TTE findings.

Methods: This study included 374 inpatients and outpatients referred to for TTE examinations. TTE studies were independently performed by second- and third-year cardiology residents, followed by reassessment by fellowship-trained attending cardiologists. The agreement of categorical variables was analyzed using Cohen's kappa coefficient, while the agreement of quantitative parameters was determined by the intraclass correlation coefficient (ICC).

Results: There was good to excellent agreement between residents and attending evaluators for most parameters, including Pericardial Effusion (PE) (κ = 0.929), Inferior Vena Cava (IVC) (κ = 0.919), and Mitral Valve Prolapse (MVP) (κ = 0.908). Moderate agreement was observed for Atrial Septal Defect (ASD) (κ = 0.496) and Bicuspid Aortic Valve (κ = 0.565). Quantitative measures demonstrated excellent reliability for Left Ventricular Ejection Fraction (LVEF) (ICC = 0.949), Pulmonary Artery Pressure (PAP) (ICC = 0.981), Tricuspid Annular Plane Systolic Excursion (TAPSE) (ICC = 0.984), and Tricuspid Regurgitation Gradient (TRG) (ICC = 0.975).

Conclusion: Majority of the echocardiographic indices were interpreted reliably by the cardiologists-in-training. However, lower levels of agreement in the interpretation of ASD and aortic valve morphology indicate that additional training on structurally complex cardiac conditions is necessary to enhance the reliability of interpretations.

Keywords: Transthoracic Echocardiography, Echocardiography Training, Cardiology Residents, Interobserver Agreement, Intraclass Correlation Coefficient, Cohen's Kappa

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Key Messages:

↑What is "already known" in this topic:

Transthoracic echocardiography serves as the cornerstone for diagnosing and managing cardiovascular disease. In teaching hospitals, initial echocardiographic interpretations are frequently conducted by cardiology residents, and discrepancies between residents and cardiologists present challenges in the diagnosis and treatment of patients. Nonetheless, data regarding the agreement on specific echocardiographic parameters remain limited.

→What this article adds:

This study demonstrates good to excellent agreement between cardiology residents and attending cardiologists regarding most echocardiographic parameters. However, it identifies lower agreement concerning ASD and BAV morphology, highlighting areas where targeted training could enhance diagnostic accuracy, particularly in complex cases and critically ill patients.

Introduction

TTE is considered an integral component of the cardiac imaging field and is recognized as one of the most commonly employed tools for diagnosing abnormalities in heart structure, ventricular function, valve diseases, and hemodynamics due to its feasibility, non-invasive nature, and cost-effectiveness (1). The results of TTE frequently influence the diagnosis, treatment, and outcomes of patients in both hospital and outpatient settings. Therefore, accurate image acquisition and interpretation are essential to ensure optimal patient care (2). Despite advancements in echocardiographic imaging and standardized reporting, interobserver variability continues to pose a significant challenge in clinical practice, potentially leading to diagnostic disagreements stemming from varying levels of experience, image quality, technological issues, and difficulties in interpreting structural heart problems (3). Such discrepancies may affect clinical decision-making and, in some cases, contribute to preventable adverse outcomes (4).

In teaching hospitals, cardiology residents frequently perform and interpret echocardiographic examinations, particularly during on-call hours and in urgent clinical settings (5). Therefore, competency in TTE acquisition and interpretation is a fundamental component of cardiology training programs, as emphasized by major educational frameworks, including the Core Cardiovascular Training Symposium (COCATS) recommendations and other professional society guidelines (6). Previous studies have demonstrated that diagnostic errors in echocardiography, although relatively uncommon, can have clinically meaningful consequences, and a portion of these errors may be preventable through structured training and supervision (7). Therefore, accurate assessment of trainee performance is essential for maintaining quality standards in echocardiographic practice and ensuring patient safety.

Despite the central role of echocardiography in cardiology training, evidence regarding the agreement between residents and attending cardiologists during routine comprehensive transthoracic echocardiography remains limited. Most previous studies have been restricted by small sample sizes, focused echocardiographic protocols, heterogeneous study designs, or assessments of image interpretation that do not consider image acquisition (8). Consequently, the real-world diagnostic concordance between cardiology trainees and attending cardiologists during formal comprehensive TTE examinations remains insufficiently characterized. Therefore, this study aimed to evaluate the agreement between cardiology residents and fellowship-trained attending cardiologists in both the acquisition and interpretation of comprehensive transthoracic echocardiography, as well as to identify specific echocardiographic parameters and patient-related factors associated with increased interpretive variability (9). We hypothesized that residents would demonstrate high agreement with attending cardiologists for routine echocardiographic parameters, but lower concordance for structurally complex abnormalities.

Methods

Study design and clinical overview

This cross-sectional observational study was conducted in the echocardiography unit of the tertiary academic Rasoul-e Akram teaching hospital during 2024. The study evaluated the concordance between cardiology residents (second- and third-year advanced cardiology trainees) and attending cardiologists in the acquisition and interpretation of TTE. For each enrolled patient, a formal comprehensive TTE examination was independently performed and interpreted by a cardiology resident as part of routine clinical care. Residents were responsible for both image acquisition and reporting. Subsequently, fellowship-trained attending cardiologists with expertise in echocardiography performed a repeat evaluation during the same clinical encounter and independently documented their interpretations. These echocardiographic views and measurements were obtained independently by the attending cardiologist during the repeat examination without using the preliminary results of the resident's examination or any written documentation. The attending cardiologist remained blinded to the preliminary interpretation and findings of the resident until after the repeat examination was completed. Both examinations took place during the same patient visit in order to avoid differences between the two exams due to time differences. Potential physiological changes between sequential examinations, including changes in heart rate, blood pressure, and loading conditions, were recognized as potential sources of measurement variability. Attending interpretations were considered the reference standard due to their subspecialty training and greater clinical echocardiography experience. Both residents and attending physicians had access to the same echocardiography equipment for each patient's assessment to minimize technical variability. Clinical interpretations were recorded independently, and data were extracted anonymously for comparison.

Study population and ethics

The study population consisted of all consecutive inpatients and outpatients referred for TTE during the year 2024. Consecutive sampling was employed to minimize selection bias. Eligible patients included adults undergoing formal TTE examinations for whom both resident and attending assessments were completed during the same clinical encounter. Prior to enrollment, the study objectives, procedures, and confidentiality safeguards were thoroughly explained to each patient. Written informed consent was obtained from all participants.

Patients were excluded if: (1) the resident and attending physician utilized different echocardiography systems during assessment; (2) the attending physician did not complete a repeat examination during the same clinical encounter; or (3) the image quality was deemed insufficient for reliable interpretation.

The study protocol was reviewed and approved by the Ethics Committee of Iran University of Medical Sciences

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(Ethics code: IR.IUMS.FMD.REC.1403.162). All procedures were conducted in accordance with the ethical standards of the institutional and national research committees and the principles of the Declaration of Helsinki. All patient information was anonymized, coded, and kept confidential, with access limited to the research team.

Material and sample size

This study included all inpatient and outpatient individuals referred to the echocardiography unit during the year 2024. Considering a type I error of 0.05, a type II error of 0.20, and proportions $p_0 = 0.285$ and $p_1 = 0.081$, the minimum required sample size was calculated using the standard formula for comparing proportions, resulting in a final sample size of 374 patients. Although the estimated minimum sample size was 374 patients, all eligible consecutive patients during the study period were included to enhance statistical precision, improve subgroup analyses, and strengthen reliability estimates.

Eligible participants included individuals hospitalized in regular wards or Intensive Care Units (ICU) who underwent TTE conducted by both cardiology residents and attending physicians trained in echocardiography fellowship.

Echocardiographic Examination All examinations consisted of formal comprehensive transthoracic echocardiographic studies rather than focused or Point-Of-Care Ultrasound (POCUS) assessments. Standard echocardiographic views and measurements were obtained in accordance with institutional routine practices and contemporary echocardiographic recommendations for chamber dimensions, ventricular function, valvular assessment, and hemodynamic measurements. All TTE studies were performed using the same echocardiography device during each patient assessment to ensure consistency in image acquisition. The echocardiographic parameters evaluated included ventricular systolic and diastolic function, valvular heart diseases, chamber size, PAP, TAPSE, TRG, IVC size, RWMA, PE, and selected structural abnormalities, including ASD and aortic valve morphology.

Statistical analysis

In this study, all statistical analyses were performed using SPSS version 23 (IBM Corp., Armonk, NY, USA). Continuous variables with a normal distribution are presented as mean ± standard deviation, while variables with a non-normal distribution are reported as median (first quartile–third quartile). Interobserver agreement for categorical echocardiographic findings was assessed using Cohen's kappa coefficient (κ), whereas agreement for continuous echocardiographic measurements was evaluated using ICC. The agreement among residents and cardiologist attendings on continuous echocardiographic measurements was assessed using a two-way random-effects, single-measurement, absolute-agreement ICC. This model was selected to assess the absolute agreement between the two raters rather than merely the consistency of their measurements ICC estimates were reported with corresponding 95% confidence intervals. ICC values were interpreted as poor (<0.50), moderate (0.50–0.75), good (0.75–0.90), or excellent (>0.90). Comparisons between second- and third-year residents were performed as exploratory analyses using independent-samples t tests or Mann–Whitney U tests for continuous variables and chi-square tests for categorical variables, as appropriate. In all analyses, P-values less than 0.05 were considered statistically significant. Agreement for continuous echocardiographic measurements, including LVEF, PAP, TRG, and TAPSE, was assessed using ICC, which indicates the level of agreement or reliability between measurements or raters (Figure 1). ICC values were interpreted as poor (<0.50), moderate (0.50–0.75), good (0.75–0.90), or excellent (>0.90) (10).

Agreement between residents and attending cardiologists for categorical echocardiographic findings was assessed using Cohen's kappa coefficient (κ). Agreement was interpreted as poor (<0.40), moderate (0.40–0.59), good (0.60–0.79), or excellent (≥0.80).

Comparisons between second- and third-year residents were performed using independent t-tests or Mann–Whitney U tests for continuous variables, and chi-square tests for categorical variables, as appropriate.

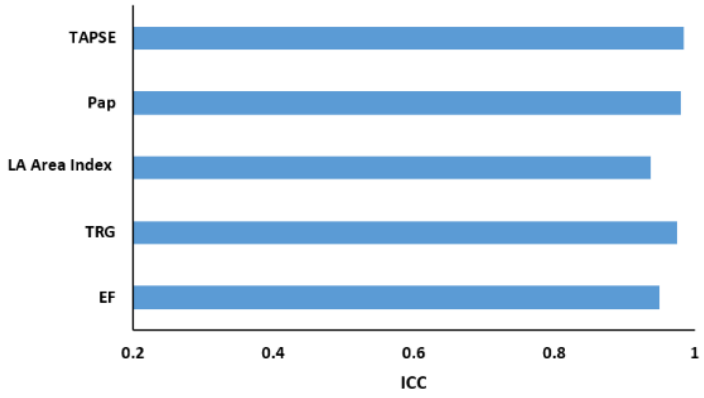

Figure 1. Intraclass correlation coefficients (ICCs) showing the agreement between cardiology residents and attending cardiologists for the assessment of left ventricular ejection fraction (EF), tricuspid regurgitation gradient (TRG), left atrial (LA) area index, pulmonary artery pressure (PAP), and tricuspid annular plane systolic excursion (TAPSE). Higher ICC values indicate stronger agreement between the residents and attending.

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Results

Baseline characteristics

The study included 374 patients with a mean age of 61 years (range 51–70). The majority were male (60%) and were primarily admitted to the ICU (52%). The most frequent indications for echocardiography were acute coronary syndrome (25%) and preoperative evaluation (24%), followed by dyspnea/pneumonia, hypertension, stroke, acute decompensated heart failure, arrhythmia, and syncope. Baseline demographic, clinical, and echocardiographic characteristics are summarized in Table 1.

Regional Wall Motion Abnormalities RWMA were most frequently identified in the inferior and inferoseptal myocardial segments across the basal and mid-left ventricular regions. Apical abnormalities were less common and predominantly involved the anterior and apical segments. The distribution of RWMA findings is presented in Table 2.

Resident–Attending Concordance Overall, the agreement between cardiology residents and attending cardiologists was good to excellent across most echocardiographic parameters (Tables 3 and 4, Figure 2). Among qualitative variables, the highest agreement was observed for pericardial effusion (κ = 0.929), IVC assessment (κ = 0.919), and mitral valve prolapse (κ = 0.908). Excellent concordance was also observed for regional wall-motion

Table 1. Baseline demographic, clinical, and echocardiographic characteristics

		Age	Weight	Height	BMI	SBP	DBP	HR
N	Valid	317	318	318	318	316	316	316
	Missing	57	56	56	56	58	58	58
Median		61.00	74.00	169.00	25.5228	125.00	80.00	80.00
Percentiles	25	51.00	65.00	160.00	22.9471	111.25	70.00	75.00
	50	61.00	74.00	169.00	25.5228	125.00	80.00	80.00
	75	70.00	80.00	175.00	28.2570	135.00	85.00	88.00
Gender								
Male					225 (60.16%)			
Female					149 (39.84%)			
Patient Admission								
Outpatient					13 (3.5%)			
General Ward					135 (36.1%)			
ICU/CCU					226 (60.4%)			
Echocardiography Indication								
Preoperative Evaluation					91 (24.33%)			
ACS					93 (24.86%)			
Stroke					17 (4.54%)			
Pneumonia					61 (16.31%)			
Hypertension					33 (8.82%)			
Arrhythmia					6 (1.60%)			
ADHF					14 (3.74%)			
Syncope					4 (1.06%)			
Total					319 (85.3%)			
Missing data					55 (14.7%)			

Table 2. The distribution of RWMA findings

Segment LV							
Basal LV	Number (%)	Mid-LV	Number (%)	Apical LV	Number (%)	LV Apex	Number (%)
1 -Anterior	6 (1.6/%)	7- Anterior	15 (4.01%)	13- Anterior	17 (4.54%)	17- Apical cap	11 (2.94%)
2- Anteroseptal	22 (5.88%)	8- Anteroseptal	31 (8.28%)	14- Apical	16 (4.27%)		
3- Inferoseptal	28 (7.48%)	9-Inferoseptal	30 (8.02%)	15- Inferior	12 (3.20%)		
4- Inferior	25 (6.68%)	10- Inferior	29 (7.75%)	16- Lateral	13 (3.47%)		
5- Inferolateral	20 (5.34%)	11- Inferolateral	26 (6.95%)				
6- Anterolateral	11 (2.94%)	12- Anterolateral	16 (4.27%)				

Table 3. Assessment of Agreement in the Severity of Abnormalities Between Attending Physicians and Residents

Parameter		Attending Physician	Resident	Kappa Coefficient	Standard Error (SE)
Abnormal LV size		16 (4.6%)	8 (2.3%)	0.570	0.121
LV diastolic dysfunction		213 (60.9%)	173 (49.4%)	0.738	0.035
Left ventricular wall motion abnormality		144 (41.1%)	128 (36.6%)	0.880	0.026
LVH		46 (13.1%)	31 (8.9%)	0.724	0.060
Abnormal RV size		40 (11.4%)	24 (6.9%)	0.727	0.064
Pericardial effusion		24 (6.9%)	21 (6.0%)	0.929	0.041
Valvular vegetation		5 (1.4%)	4 (1.1%)	0.887	0.112
Intracardiac thrombus		7 (2.0%)	5 (1.4%)	0.831	0.118
MVP		6 (1.7%)	5 (1.4%)	0.908	0.092
IVC		21 (6.0%)	18 (5.1%)	0.919	0.047
Abnormal left atrial (LA) size		10 (2.9%)	9 (2.6%)	0.838	0.092
AV	Bicuspid valve	8 (2.3%)	3 (0.9%)	0.565	0.159
	Tricuspid valve	341 (97.4%)	345 (98.6%)		
MV		6 (1.7%)	5 (1.4%)	0.765	0.131
Atrial septal defect (ASD)		6 (1.7%)	2 (0.6%)	0.496	0.216

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Table 4. Assessment of Interobserver Agreement between Attending Physicians and Residents

Parameter		Attending Physician	Resident	Kappa Coefficient	Standard Error
RV function	Normal function	284 (81.1%)	302 (86.3%)	0.686	0.047
	Mild dysfunction	48 (13.7%)	43 (12.3%)		
	Moderate dysfunction	17 (4.9%)	5 (1.4%)		
	Severe dysfunction	1 (0.3%)	0		
MR	Normal	9 (2.6%)	16 (4.6%)	0.742	0.031
	Trace	84 (24.0%)	96 (27.4%)		
	Mild	190 (54.3%)	192 (54.9%)		
	Mild to Moderate	43 (12.3%)	39 (11.1%)		
	Moderate	21 (6.0%)	7 (2.0%)		
	Moderate to Severe	2 (0.6%)	0		
	Severe	1 (0.3%)	0		
MS	Normal	341 (97.4%)	342 (97.7%)	0.463	0.079
	Trace	1 (0.3%)	0		
	Mild	0	3 (0.9%)		
	Mild to Moderate	0	3 (0.9%)		
	Moderate	4 (1.1%)	2 (0.6%)		
	Moderate to Severe	0	0		
	Severe	4 (1.1%)	0		
AI	Normal	241 (68.9%)	254 (72.6%)	0.692	0.034
	Trace	28 (8.0%)	35 (10.0%)		
	Mild	46 (13.1%)	43 (4.3%)		
	Mild to Moderate	23 (6.6%)	15 (0.6%)		
	Moderate	10 (2.9%)	2 (0.3%)		
	Moderate to Severe	0	0		
	Severe	2 (0.6%)	1 (0.3%)		
AS	Normal	334 (95.5%)	339 (96.9%)	0.770	0.087
	Trace	14 (4.0%)	9 (2.6%)		
	Mild	1 (0.3%)	1 (0.3%)		
	Mild to Moderate	0	0		
	Moderate	0	1 (0.3%)		
	Moderate to Severe	0	0		
	Severe	1 (0.3%)	0		
TR	Normal	10 (2.9%)	20 (5.7%)	0.706	0.031
	Trace	104 (29.7%)	123 (35.1%)		
	Mild	171 (48.9%)	164 (46.9%)		
	Mild to Moderate	44 (12.6%)	34 (9.7%)		
	Moderate	16 (4.6%)	9 (2.6%)		
	Moderate to Severe	2 (0.6%)	0		
	Severe	3 (0.9%)	0		
TS	Normal	349 (99.7%)	349 (99.7%)	1	<0.001
	Trace	0	0		
	Mild	0	0		
	Mild to Moderate	1 (0.3%)	1 (0.3%)		
	Moderate	0	0		
	Moderate to Severe	0	0		
	Severe	0	0		
PI	Normal	103 (29.4%)	124 (35.4%)	0.826	0.029
	Trace	221 (63.1%)	203 (58.0%)		
	Mild	18 (5.1%)	18 (5.1%)		
	Mild to Moderate	6 (1.7%)	5 (1.4%)		
	Moderate	2 (0.6%)	0		
	Moderate to Severe	0	0		
	Severe	0	0		
PS	Normal	347 (99.1%)	347 (99.1%)	1	0.031
	Trace	3 (0.9%)	3 (0.9%)		
	Mild	0	0		
	Mild to Moderate	0	0		
	Moderate	0	0		
	Moderate to Severe	0	0		
	Severe	0	0		
PH	Normal	279 (79.7%)	284 (81.1%)	0.916	0.026
	Mild	38 (10.9%)	36 (10.3%)		
	Moderate	17 (4.9%)	18 (5.1%)		
	Severe	16 (4.2%)	12 (3.2%)		

abnormalities and valvular vegetations. In contrast, lower agreement was identified for ASD (κ = 0.496) and BAV morphology (κ = 0.565), indicating moderate concordance. Agreement for valvular heart disease grading was generally good, including mitral regurgitation (κ = 0.742), aortic stenosis (κ = 0.770), tricuspid regurgitation (κ = 0.706), pulmonary insufficiency (κ = 0.826), and pulmonary hypertension (κ = 0.916). Lower agreement was ob-

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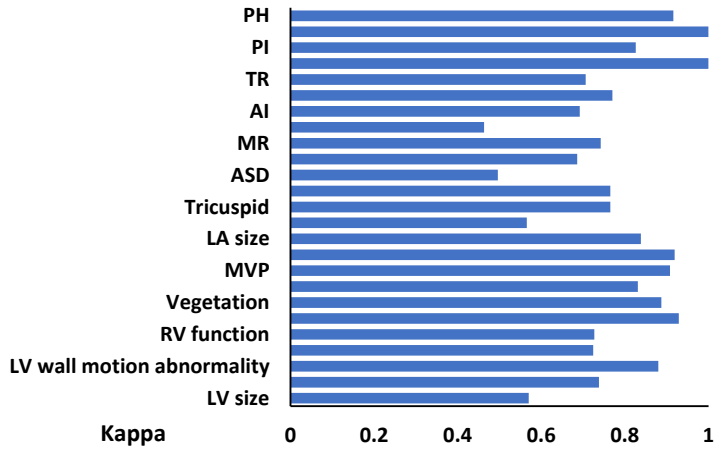

Figure 2. Agreement between cardiology residents and attending cardiologists. Higher ICC values indicate stronger agreement between the residents and attending.

served for mitral stenosis (κ = 0.463), likely reflecting the relative rarity and complexity of this finding. For quantitative echocardiographic measurements, excellent reliability was observed for left ventricular ejection fraction (ICC = 0.949), pulmonary artery pressure (ICC = 0.981), tricuspid annular plane systolic excursion (TAPSE; ICC = 0.984), tricuspid regurgitation gradient (ICC = 0.975), and left atrial area index (ICC = 0.937). Due to the limited number of available measurements, agreement analysis for global longitudinal strain (GLS) could not be reliably performed. Comparison Between Second- and Third-year residents. No major differences were observed between second- and third-year cardiology residents in the interpretation of most echocardiographic parameters (Table 5).

Similar performance was noted in the assessment of left ventricular diastolic dysfunction, regional wall-motion abnormalities, ventricular function, and most valvular abnormalities. Statistically significant differences in the evaluation of mitral stenosis and pulmonary hypertension were noted in a few cases, where third-year residents performed relatively better. However, quantitative echocardiographic parameters, including EF, PAP, TAPSE, and left atrial area index, showed no statistically significant differences between resident groups. Subgroup Analyses Subgroup analyses demonstrated lower resident–attending agreement among patients admitted to the ICU and in those with obesity, enlarged left atrial size, or impaired GLS (Figure 3). This indicates that patient complexity and suboptimal imaging conditions may contribute to greater variability in interpretation. However, overlap between subgroup characteristics should be considered when interpreting these findings.

Discussion

This research study determined the level of correlation between cardiology residents and fellowship-trained attending cardiologists regarding the acquisition and interpretation of comprehensive TTE. The results revealed that: 1- there is a good to excellent level of concordance for most echocardiographic indices; 2- quantifiable data such as LVEF, PAP, TAPSE, and TRG showed very high reliability; 3- lower concordance was observed for structurally complex abnormalities, such as ASD and BAV morphology; and 4- agreement was reduced in clinically complex scenarios, such as ICU patients and those with challenging imaging conditions. The high level of agreement found for routine echocardiographic parameters is consistent with previous studies reporting strong interobserver reliability between trainees and expert echocardiographers for standard quantitative measurements such as LVEF and right ventricular function (11). These parameters are generally well standardized, less operator-dependent, and supported by clear measurement guidelines, which may explain the high reproducibility observed in this study. In concordance with the study by Labovitz et al., structured cardiology training programs and repeated exposure to common echocardiographic findings likely contribute to improved consistency between residents and attending physicians. In contrast, lower agreement was observed for ASD and BAV morphology. These findings align with previous reports indicating that congenital or structurally complex cardiac abnormalities are associated with higher interobserver variability due to subtle anatomical features, imaging dependability, and increased expertise required for accurate diagnosis (12). The misdiagnosis of these anomalies could also be attributed to a lack of experience in managing such conditions. The reduced agreement observed in ICU patients and individuals with poor echocardiographic windows or abnormal cardiac geometry (e.g., enlarged LA or impaired GLS) is also consistent with previous studies. Critical illness, mechanical ventilation, and unstable hemodynamics can significantly affect image quality and measurement reproducibility, thus increasing variability between observers. These findings highlight the importance of supervised interpretation in critically ill populations (3, 13). In concordance with the study by Farsi et al., excellent agreement was observed for TRG; however, this parameter may still be influenced by loading conditions, respiratory variation, and transient hemodynamic

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Table 5. Compression between second- and third-year cardiology residents' echocardiographic interpretations

Parameter		Second-year residents (n = 285)	Third-year residents (n = 66)	*P*-value
Abnormal LV size		5 (1.7%)	3 (4.5%)	0.361
LV diastolic dysfunction		136 (47.9%)	37 (56.1%)	0.274
LV wall motion abnormalities		105 (37.0%)	23 (34.8%)	0.778
LVH		24 (8.5%)	7 (10.6%)	0.630
Abnormal RV size		22 (7.7%)	3 (4.5%)	0.440
Pericardial effusion		18 (6.3%)	3 (4.5%)	0.776
Infective valvular mass (vegetation)		4 (1.4%)	0	0.594
Intracardiac thrombus		4 (1.4%)	1 (1.5%)	1
MVP		4 (1.6%)	1 (1.6%)	1
IVC		16 (5.6%)	2 (3.0%)	0.543
Abnormal LA size		9 (3.2%)	0	0.218
AV	Bicuspid valve	3 (1.1%)	0	0.753
	Tricuspid valve	279 (98.2%)	66 (100%)	
MV		5 (1.4%)	0	0.666
ASD		2 (0.6%)	0	1
RV	Normal function	244 (85.6%)	60 (89.6%)	0.537
	Mild dysfunction	36 (12.6%)	7 (10.4%)	
	Moderate dysfunction	5 (1.8%)	0	
	Severe dysfunction	0	0	
MS	Normal	280 (98.6%)	62 (93.9%)	0.016
	Trace	0	0	
	Mild	1 (0.4%)	2 (3.0%)	
	Mild to moderate	3 (1.1%)	0	
	Moderate	0	2 (3.0%)	
	Moderate to severe	0	0	
	Severe	0	0	
AI	Normal	204 (71.8%)	50 (75.8%)	0.452
	Trace	27 (9.5%)	8 (12.1%)	
	Mild	35 (12.3%)	8 (12.1%)	
	Mild to moderate	15 (5.3%)	0	
	Moderate	2 (0.7%)	0	
	Moderate to severe	0	0	
	Severe	1 (0.4%)	0	
AS	Normal	273 (95.8%)	66 (100%)	0.582
	Trace	9 (3.2%)	0	
	Mild	1 (0.4%)	0	
	Mild to moderate	1 (0.4%)	0	
	Moderate	1 (0.4%)	0	
	Moderate to severe	0	0	
	Severe	0	0	
TR	Normal	14 (4.9%)	6 (9.1%)	0.499
	Trace	97 (34.0)	26 (39.4)	
	Mild	138 (48.4%)	26 (39.4%)	
	Mild to moderate	28 (9.8%)	7 (10.6%)	
	Moderate	8 (2.8%)	1 (1.5%)	
	Moderate to severe	0	0	
	Severe	0	0	
TS	Normal	283 (99.6%)	66 (100%)	
	Trace	0	0	1
	Mild	0	0	
	Mild to moderate	1 (0.4%)	0	
	Moderate	0	0	
	Moderate to severe	0	0	
	Severe	0	0	
PI	Normal	99 (34.7%)	25 (37.9%)	0.629
	Trace	168 (58.9%)	36 (54.5%)	
	Mild	15 (5.3%)	3 (4.5%)	
	Mild to moderate	3 (1.1%)	2 (3.0%)	
	Moderate	0	0	
	Moderate to severe	0	0	
	Severe	0	0	
PS	Normal	282 (99.3%)	65 (98.5%)	1
	Trace	2 (0.7%)	1 (1.5%)	
	Mild	0	0	
	Mild to moderate	0	0	
	Moderate	0	0	
	Moderate to severe	0	0	
	Severe	0	0	
PH	Normal	225 (78.9%)	59 (89.4%)	0.026
	Mild	34 (11.9%)	2 (3.0%)	
	Moderate	14 (4.9%)	4 (6.1%)	
	Severe	12 (4.2%)	1 (1.5%)	
EF		55 (5-62.5)	55 (20-55)	0.787
TRG		22 (0-98)	20 (0-52)	0.086
LA area index		19 (12-40)	17 (12-45)	0.586
Pap		26 (0-105)	25 (0-62)	0.137
TAPSE		17 (0-30)	18 (0-30)	0.151

changes. Therefore, minor discrepancies between residents and attending cardiologists may reflect not only interpretive differences but also physiological variability at the time of examination (14). Overall, the results from

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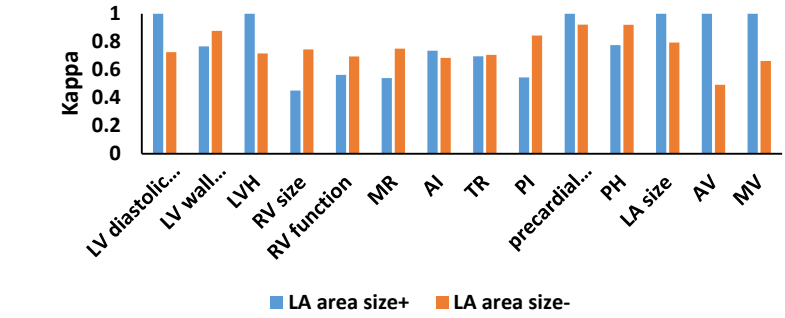
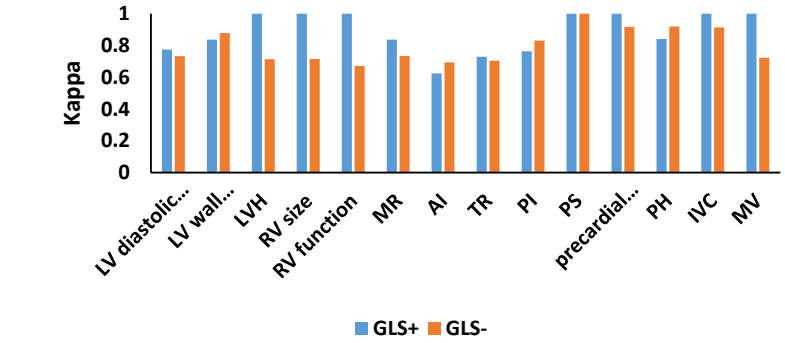


A



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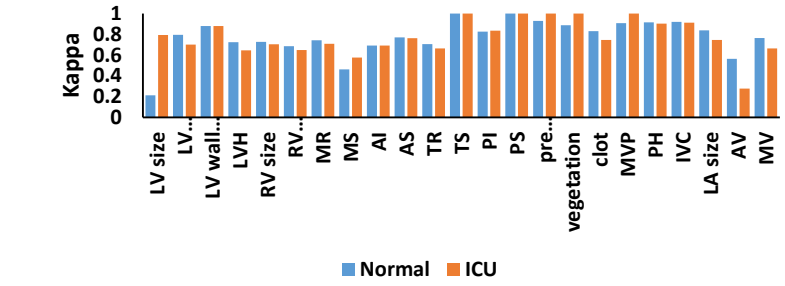

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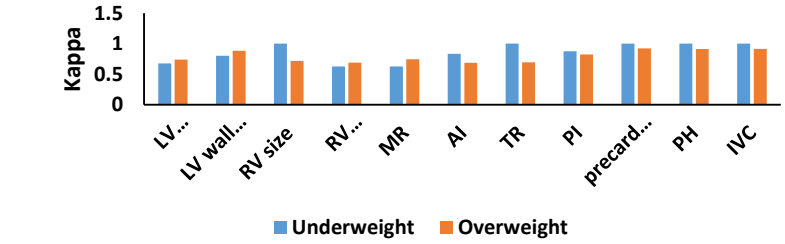

D

Figure 1. Subgroup analysis of the interobserver agreement (Cohen's kappa) between residents and attending cardiologists for echocardiographic parameters. The bar charts compare Cohen's kappa coefficients for each echocardiographic parameter across different patient subgroups. (A) Subgroup 1: patients with enlarged left atrial (LA) area (LA area size+) versus normal LA area (LA area size−). (B) Subgroup 2: patients with impaired global longitudinal strain (GLS+) versus preserved global longitudinal strain (GLS−). (C) Subgroup 3: intensive care unit (ICU) patients versus non-ICU (normal ward) patients. (D) Subgroup 4: underweight versus overweight patients. Higher kappa values indicate greater agreement between residents and attending cardiologists.

this study indicate that the residents involved are competent in measuring and interpreting echocardiographic measurements, particularly in quantitative assessments. However, targeted training focused on structural abnormalities and challenging clinical scenarios may further enhance diagnostic consistency and reduce interobserver variability. Limitations of this study include its single-center design and potential variability in image quality across different clinical settings. Moreover, while the attending interpreter was considered the gold standard in this study, there is the possibility of some intra-observer variation among experts that cannot be ruled out. Finally,

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this study did not evaluate the long-term learning curves of residents, which may be important for understanding progressive skill acquisition.

Limitations

This study has several limitations that must be considered. Firstly, it was conducted at a single tertiary academic center, which may impact its generalizability to other institutions with varying levels of experience or differing methodologies. Secondly, although attending cardiologists were regarded as the reference standard, intra-rater variability among them was not assessed. Thirdly, variability in image quality and acquisition conditions across different clinical settings, particularly in critically ill patients, may have influenced inter-rater variability. Fourth, this study did not assess the longitudinal learning curve of residents, which could offer additional insights into the progressive acquisition of skills over time. Additionally, the prior echocardiographic experience of individual residents was not systematically recorded. Specifically, the number of TTE examinations previously performed or interpreted by each resident was not available for analysis; therefore, potential differences in individual experience could not be adjusted for and may have contributed to the observed variability. Also, even though cases with poor image quality were not included in the study, there could have been some variability in the image quality of those that were included. This could have affected interobserver agreement and represented a potential source of unmeasured confounding. Finally, potential selection bias cannot be entirely ruled out, as some studies may have been affected by clinical urgency or suboptimal imaging conditions that were not consistently controlled.

Conclusion

This study demonstrates that cardiology residents can perform comprehensive transthoracic echocardiographic measurements with good to excellent agreement when compared to fellowship-trained attending cardiologists. Overall, the findings support the feasibility of resident-performed echocardiographic evaluations in routine clinical practice within teaching hospitals.

Nonetheless, poor agreement was observed in cases involving more complex cardiac structural pathologies, such as atrial septal defects and bicuspid aortic valve, as well as in challenging scenarios involving the assessment of critically ill patients in ICU. This highlights the need for targeted educational initiatives in this area. Ultimately, enhancing structured echocardiography training programs may improve diagnostic accuracy, elevate the quality of patient care, and reduce interobserver variability.

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Conflict of Interests

The authors declare that they have no competing interests.

Authors' Contributions

Soroush Mostafavi, Leila Nojoomizadeh, and Hamzeh Habibi contributed to the study design and methodology. Arefeh Samanifard, Aynaz Panahi, and Sara Bakhtiari were responsible for data collection, analysis, and interpretation of the study. Additionally, Abdolfattah Mohtashami, Seyede Saba Mostafavi Montazeri, and Seyedeh Sarvin Mostafavi Montazeri contributed to the writing and editing of the manuscript. Pegah Joghataie and Mahmboubeh Pazoki contributed to the writing and conceptualization.

Ethical Considerations

This manuscript was derived from a thesis that received ethical approval from the Iranian National Committee for Ethics in Biomedical Research (Approval Code: IR.IUMS.FMD.REC.1403.162).

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Data Availability

The data from this study is available from the corresponding author upon reasonable request.

AI Use Statement

The authors did not use artificial intelligence

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