Original Paper

Accuracy of Left Ventricular Ejection Fraction Assessment by Noncardiologists E-Point Septal Separation and Teichholz Methods: Simulation-Based Pre-Post Training Study

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Abstract

Background: Point-of-care ultrasound (POCUS) enables rapid bedside estimation of left ventricular ejection fraction (LVEF) in the emergency department. Among quantitative methods, E-point septal separation (EPSS) and Teichholz-derived calculations are commonly used; however, their comparative accuracy when performed by noncardiologist clinicians remains unclear.

Objective: This study aimed to compare the accuracy and efficiency of EPSS and Teichholz-based methods for LVEF assessment by emergency department physicians, using the Simpson biplane method as the reference standard.

Methods: We conducted a prospective pre-post interventional study using standardized patients (SPs) at a university simulation training unit (March 2025). Following prerecorded lectures and demonstration videos, emergency department physicians (n=26) measured LVEF using three bedside methods—EPSS, Teichholz long-axis, and Teichholz short-axis—before and after a focused hands-on training session including supervised image acquisition and guided LVEF measurement. Five SPs with cardiologist-confirmed LVEF values ranging from 16% to 73% were used across the study assessments. The primary outcome was the absolute difference between participant-measured and reference LVEF. Secondary outcomes included time-to-completion and participant-reported confidence for each method.

Results: Before training, EPSS demonstrated a significantly lower absolute error (median 5 percentage points, IQR 3-13) compared with Teichholz long-axis (17 percentage points, IQR 9-27) and Teichholz short-axis (13 percentage points, IQR 4-24) methods (P=.009). EPSS also required less time (median 73 seconds, IQR 53-121) than Teichholz long-axis (150 seconds, IQR 103-200) and Teichholz short-axis (100 seconds, IQR 67-184) (P=.02). After training, no statistically significant difference in absolute LVEF error was detected among methods in the preserved-LVEF assessment (P=.93). In the posttraining reduced-LVEF assessment, no statistically significant difference in absolute LVEF error was detected among methods in the SP with an LVEF of 48% (P=.48). In contrast, in the single SP with an LVEF of 16%, absolute LVEF error differed significantly among methods (P=.008), with greater error for EPSS (median 30.5 percentage points) than for Teichholz long-axis (11 percentage points) and Teichholz short-axis (8 percentage points). EPSS remained the fastest technique in preserved (62 seconds; P<.001) and reduced LVEF cases (79 seconds; P<.001). Confidence scores improved across all methods, with EPSS demonstrating the highest median posttraining confidence (P=.01). Greater variability in EPSS measurements was observed in reduced LVEF, with a mean bias of −16 (SD 23) percentage points and wide 95% limits of agreement from −61.1 to 29.1.

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Conclusions: Following focused ultrasound training, no statistically significant difference in absolute LVEF error was detected among methods in the preserved-LVEF assessment or in the SP with an LVEF of 48%. However, EPSS demonstrated greater error than both Teichholz methods in the single SP with an LVEF of 16%, a case-specific finding that should be considered hypothesis-generating. EPSS required less time to perform and was associated with higher learner confidence.

Trial Registration: Thai Clinical Trials Registry TCTR20250123008; https://tinyurl.com/3kphcru3

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KEYWORDS

point-of-care ultrasound; left ventricular ejection fraction; E-point septal separation; Teichholz method; emergency medicine; simulation-based training

Introduction

Left ventricular ejection fraction (LVEF) is a fundamental indicator of cardiac systolic function and plays a critical role in the evaluation and management of critically ill patients [1-3]. In emergency settings, rapid assessment of LVEF is particularly important for differentiating the causes of undifferentiated shock and acute dyspnea, guiding vasoactive therapy, and identifying acute heart failure [4-7]. Recognizing the need for timely bedside cardiac assessment, point-of-care ultrasound (POCUS) has been widely adopted by noncardiologist clinicians to evaluate cardiac function in acute care settings [8,9]. Bedside cardiac POCUS provides a focused, real-time assessment of left ventricular performance when physical examination alone may be insufficient, thereby enhancing early diagnostic accuracy and supporting resuscitation decisions in critically ill patients [1,9].

The modified Simpson biplane method is considered the reference standard for LVEF measurement because it directly calculates ventricular volumes from endocardial tracings [10]. However, this method requires precise apical imaging, careful endocardial border tracing, and substantial operator experience, making it less practical for rapid bedside assessment in emergency settings.

In clinical practice, simplified quantitative methods are commonly used during POCUS to allow faster LVEF estimation. Two widely used approaches are the Teichholz method and the mitral valve E-point septal separation (EPSS) [11,12]. The Teichholz method estimates LVEF from left ventricular internal dimensions measured during systole and diastole using M-mode imaging, typically obtained in parasternal views. This technique is relatively simple but depends on geometric assumptions of ventricular shape and accurate image alignment, which may introduce error in patients with abnormal ventricular geometry or regional wall-motion abnormalities [10,11,13].

EPSS, on the other hand, is a single M-mode measurement that has gained popularity in emergency medicine due to its simplicity and speed. EPSS is obtained in the parasternal long-axis view by measuring the minimal distance between the anterior mitral valve leaflet and the interventricular septum during early diastole [12]. This distance is inversely correlated with LVEF—a smaller EPSS (ie, the mitral leaflet nearly touching the septum) indicates vigorous systolic function, whereas a larger EPSS reflects worse LV systolic function. For example, McKaigney et al [14] reported an EPSS threshold >7 mm for identifying severe left ventricular systolic dysfunction (LVEF ≤30%), whereas Núñez-Ramos et al [15] identified 9.5 mm as the optimal cutoff for detecting LVEF ≤40% and reported that a higher threshold of 13.5 mm provided high specificity (94.2%) for LVEF ≤40%. Prior studies have demonstrated an inverse relationship between EPSS and LVEF and have supported its use by emergency physicians as a rapid bedside marker of reduced systolic function [14]. However, the accuracy of quantitative LVEF derived from EPSS relative to other simplified bedside methods remains uncertain.

Despite the widespread use of both Teichholz-based calculations and EPSS in point-of-care cardiac ultrasound, their relative accuracy when performed by noncardiologist clinicians has not been well established. Most prior studies have evaluated these techniques independently or compared POCUS-derived estimates with formal echocardiography, rather than directly comparing simplified quantitative methods under standardized acquisition conditions. As a result, uncertainty remains regarding which bedside method provides the most reliable and operationally feasible estimation of LVEF when applied by frontline clinicians.

Therefore, this study aimed to compare LVEF estimates obtained by emergency clinicians using three bedside methods—Teichholz long-axis, Teichholz short-axis, and EPSS—against the reference standard biplane Simpson method. We further aimed to compare their measurement accuracy, time-to-completion, and learner confidence. We hypothesized that LVEF measurement accuracy would differ between EPSS and Teichholz-based methods when performed by noncardiologist clinicians.

Methods

Study Design

We conducted a prospective pre-post interventional study at the simulation training unit, Faculty of Medicine, Khon Kaen University, Thailand, in March 2025. Reporting of this study was guided by the STARD (Standards for Reporting Diagnostic Accuracy Studies) and TIDieR (Template for Intervention Description and Replication) checklists, where applicable. Because this was a quantitative method-comparison study rather than a diagnostic classification study, STARD items related specifically to diagnostic positivity thresholds and cross-tabulation were considered not applicable. The trial was registered with the Thai Clinical Trials Registry (TCTR; ID: TCTR20250123008) on January 23, 2025

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(https://www.thaiclinicaltrials.org/show/TCTR20250123008). The registered primary outcome was accuracy of LVEF measurement, defined as the difference between participant-measured LVEF and the cardiologist-performed Simpson reference, and the registered secondary outcome was participant confidence. Measurement time was collected prospectively during the study but was not prespecified as an outcome in the trial registration. SP-specific and agreement analyses were conducted post hoc during peer review to further characterize the observed findings.

Participants

Participants were recruited through announcements posted on the university's official Facebook page. Eligible participants were physicians currently working in the emergency department. Board-certified cardiologists were excluded. Written informed consent was obtained from all participants prior to enrollment. Participation was voluntary, and no financial compensation or incentives were provided.

Study Procedure

All participants underwent a structured training session that included:

1. Prerecorded lectures and demonstration videos on the EPSS and Teichholz methods were provided. These instructional videos were developed by the study team specifically for educational purposes and were presented in Thai. The videos were 15 minutes in duration and included detailed explanations of the measurement principles, image acquisition techniques, and step-by-step demonstrations of LVEF calculation using both methods. Participants were required to review the video prior to the hands-on training session to ensure adequate baseline knowledge. The instructional video is available at [16]. The instructional video was presented in Thai. YouTube closed captions are available through the platform, and a short English transcript prepared by the study authors is provided in the YouTube video description.
2. Pretraining assessment: On the study day, participants first completed a pretraining assessment using one randomly assigned standardized patient (SP). Participants independently performed cardiac ultrasound examinations and measured LVEF using the EPSS, Teichholz long-axis, and Teichholz short-axis methods without guidance or feedback from the study team.
3. Hands-on training session: Following the pretraining assessment, participants underwent structured hands-on training delivered by 4 physician trainers comprising three emergency physicians and one cardiologist. Training was conducted at 4 identically equipped stations, with one trainer supervising one participant at a time (trainer-to-learner ratio 1:1). Each participant received 15 minutes of supervised deliberate practice in EPSS and 15 minutes in the Teichholz methods, with the latter covering both long-axis and short-axis approaches, resulting in a total hands-on contact time of 30 minutes per learner. Training included live demonstration, guided image acquisition, standardized measurement procedures, supervised deliberate practice, standardized instructor prompts, and immediate corrective feedback. Intervention standardization was supported by use of the same instructional materials, measurement guidelines, and predefined training procedures across stations; however, no formal quantitative assessment of training fidelity was performed. The complete standardized training protocol is provided in
Multimedia Appendix 1
.
4. Posttraining assessment: Following the hands-on training session, each participant completed 2 posttraining assessments: one using an SP with preserved LVEF (≥50%) and one using an SP with reduced LVEF (<50%). These SPs were different individuals from those used during the training session. Participants independently performed LVEF measurements using all three methods (EPSS, Teichholz long-axis, and Teichholz short-axis) without guidance or feedback from the study team.

LVEF Measurement

LVEF from EPSS was estimated using the previously published linear equation: LVEF = 75.5 − 2.5 × EPSS (mm). The equation was derived by Silverstein et al [12] in a cohort of 42 patients using EPSS measured on cardiac magnetic resonance images, with a reported standard error of estimate of approximately 9-10 LVEF percentage points. LVEF values from both the Teichholz long-axis and Teichholz short-axis methods were automatically calculated using the built-in software of the ultrasound systems. All echocardiographic assessments were performed using either the Venue Go or Venue Fit ultrasound system (GE HealthCare), equipped with phased-array transducers (2-5 MHz). Ultrasound-system assignment was not randomized; participants used the system available at their assigned assessment station. The same standardized measurement procedures were applied on both systems. Each participant performed LVEF measurements using all 3 methods before and after training. A research assistant randomly assigned participants to the available SPs. No computer-generated allocation sequence was used. The order of the 3 LVEF measurement methods was not randomized. All participants performed the measurements in the same predefined sequence: EPSS, followed by Teichholz long-axis and Teichholz short-axis.

SPs

Five SPs were recruited from the echocardiography clinic at the Faculty of Medicine, Khon Kaen University. All SPs were adult males who were informed about the study and provided consent to participate. SPs were initially categorized based on their most recent formal echocardiography reports performed within the preceding 6 months. On the study day, LVEF was confirmed before participant assessment by a board-certified cardiologist using the biplane Simpson method. The cardiologist was blinded to participant measurements, and these values served as the reference standard. Patients with significant mitral valve disease, septal abnormalities, or severe ventricular hypertrophy were excluded to avoid confounding factors that could affect LVEF measurement accuracy.

Five SPs representing a spectrum of left ventricular systolic function were included, with reference LVEFs ranging from 16% to 73%. In the posttraining preserved-LVEF assessment,

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participants were assigned to 1 of 3 SPs with reference LVEFs of 61%, 70%, or 73%. In the posttraining reduced-LVEF assessment, participants were assigned to one of 2 SPs with reference LVEFs of 16% or 48%. SP allocation was arranged such that no participant was assessed on the same SP in more than one assessment phase. Detailed SP allocation and participant-level measurements are provided in Table S1-S3 in Multimedia Appendix 2.

Data Collection

For each measurement attempt, the LVEF value and time required to complete the assessment were recorded by a trained research assistant using the REDCap (Vanderbilt University) system. If a participant was unable to obtain an LVEF measurement within 5 minutes, the attempt was recorded as missing (NA). After completing each method, participants self-rated their confidence using a 10-point Likert scale (0=no confidence, 10=highest confidence). Participant baseline characteristics, including age, sex, training level, and prior experience with LVEF measurement, were collected at enrollment.

Outcome

The registered primary outcome was LVEF measurement accuracy, defined as the difference between the LVEF measured by participants using each technique (EPSS, Teichholz long-axis, and Teichholz short-axis) and the LVEF measured by a cardiologist using the Simpson method. The registered secondary outcome was participant-reported confidence. Measurement time was prospectively collected during the study but was not prespecified as an outcome in the trial registration.

Sample Size Calculation

Based on established heart failure classification thresholds [17] (HFrEF ≤ 40%, HFmrEF 41%-49%, HFpEF ≥ 50%), a difference of 10 percentage points in LVEF was considered clinically meaningful, as it may alter heart failure classification and management decisions.

A minimum of 23 participants was required to detect a 10-percentage-point difference in LVEF measurement error between methods, assuming an SD of 15 percentage points, 80% power, and a 2-sided significance level of .05. The assumed SD was an a priori planning assumption rather than an estimate derived from a specific published study. The calculation was not designed for a specific pairwise method comparison or assessment timepoint and did not incorporate adjustment for multiplicity across methods, LVEF strata, or secondary outcomes. The recruitment target was increased by approximately 20% to account for dropout or incomplete measurements.

Statistical Analysis

All statistical analyses were performed using R (version 4.5.2; R Foundation for Statistical Computing). Descriptive statistics were used to summarize participant characteristics. We presented continuous variables as medians with IQRs because they were nonnormally distributed. The first and third quartiles were calculated using R's type 7 sample quantile definition. We presented categorical variables as frequencies and percentages. The Friedman test was used to compare repeated measures across the three LVEF measurement methods (EPSS, Teichholz long-axis, and Teichholz short-axis) for absolute LVEF difference, time required, and confidence scores, both pre- and posttraining. Method-specific descriptive analyses were based on all available measurements, whereas Friedman tests requiring observations from all three methods were conducted using complete cases.

For significant Friedman omnibus tests, post-hoc pairwise comparisons were performed using paired Wilcoxon signed-rank tests using the normal approximation with continuity correction, with Holm adjustment for multiple comparisons. Kendall's W and matched-pairs rank-biserial correlations were reported as effect sizes for the omnibus and pairwise comparisons, respectively. All participant-generated measurements were analyzed as recorded, including measurements resulting in calculated LVEF values outside the physiologic range. These values were not truncated at physiologic boundaries or excluded because they represented observed measurement performance.

We also assessed agreement between each bedside method and the cardiologist-performed Simpson method using Bland-Altman analysis. Mean bias was calculated as the participant-measured LVEF minus the reference LVEF, with 95% limits of agreement (LoA) calculated as the mean bias (1.96 SD) of the differences. We assessed proportional bias by linear regression of the measurement difference on the mean of the bedside and reference measurements. Absolute agreement was additionally assessed using a two-way random-effects, single-measure intraclass correlation coefficient [ICC(2,1)].

Exploratory subgroup analyses were conducted according to training level (resident, intern/general practitioner, or board-certified emergency physician) and prior LVEF measurement experience (never, occasionally, or regularly). Absolute LVEF error, measurement time, and confidence were summarized within each subgroup using medians and IQRs, and between-group differences were assessed using the Kruskal-Wallis test. In addition, within-participant changes from pretraining to each posttraining assessment were calculated. For absolute LVEF error and measurement time, change was defined as the pretraining value minus the posttraining value, such that positive values indicated reduced error or shorter measurement time. For confidence, change was defined as the posttraining value minus the pretraining value, such that positive values indicated increased confidence. Paired pre- and posttraining values were compared using the Wilcoxon signed-rank test. These within-participant analyses were considered exploratory because different SPs with different case characteristics were used across assessment phases. Within-participant changes were not further stratified by participant subgroup because the resulting subgroup sizes would have been small and the estimates unstable. Normalized learning gain was not calculated because pre- and posttraining performance was assessed using different SPs and because the primary performance outcome was absolute LVEF measurement error rather than a bounded educational score with a defined maximum. Therefore, the observed within-participant changes may reflect both changes following training and differences in

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case characteristics and should not be interpreted as isolated effects of the training intervention.

A 2-sided $P<.05$ was considered statistically significant. Boxplots were generated to visualize the distribution of LVEF measurement differences for each method before and after training, compared with the Simpson method.

Ethical Considerations

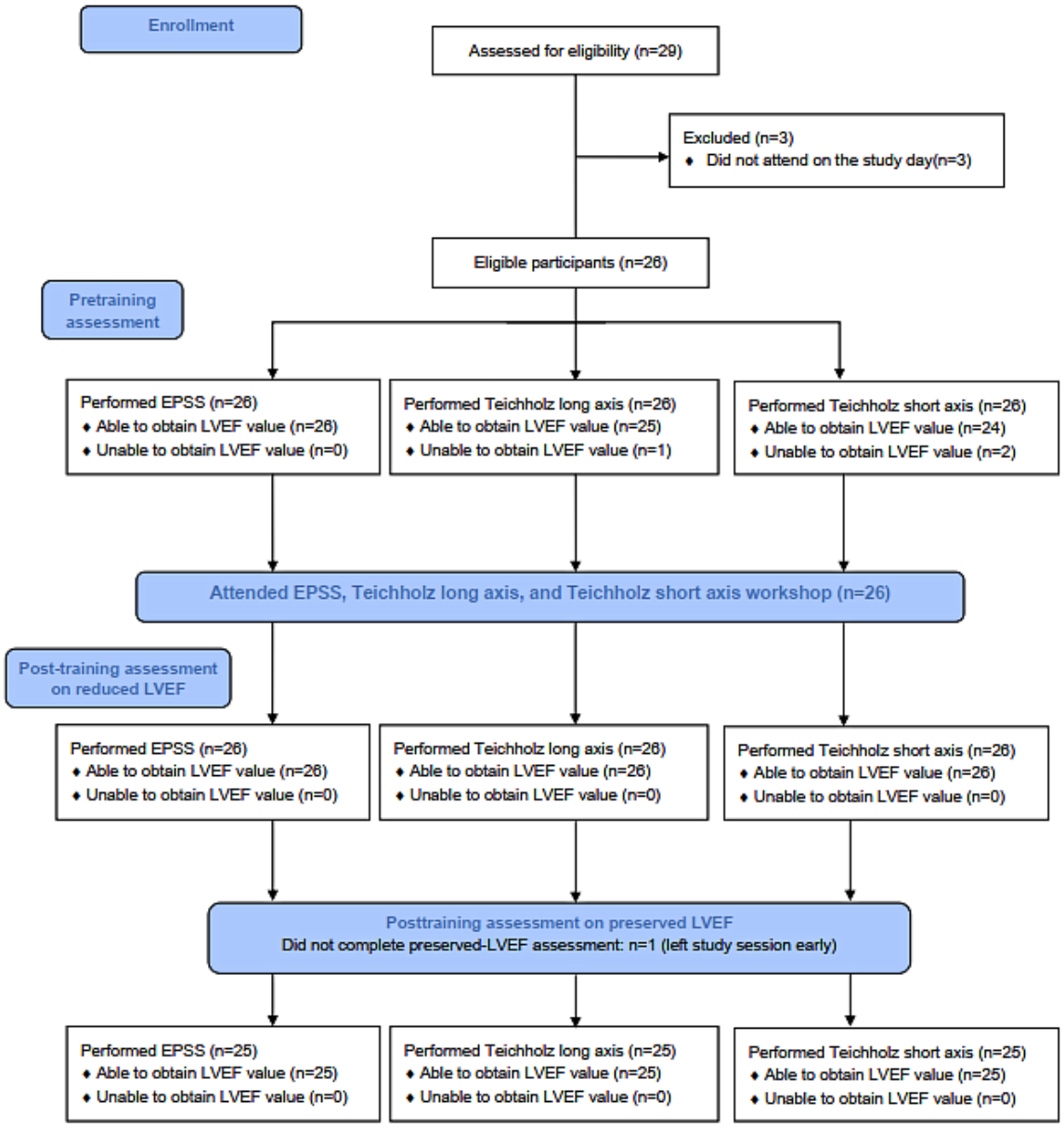
Written informed consent was obtained from all participants prior to enrollment. The study was conducted in accordance with the principles of the Declaration of Helsinki and Good Clinical Practice guidelines. Ethical approval was granted by the Khon Kaen University Ethics Committee in Human Research (HE671550).

Results

Participant Characteristics

A total of 29 eligible participants were invited to participate, of whom 26 attended the study session and were enrolled (Figure 1). Three eligible participants did not attend on the study day and were therefore not included in the final analysis. All 26 completed the posttraining reduced-LVEF assessment, whereas 25 participants completed the posttraining preserved-LVEF assessment. One participant left the study session early and therefore did not complete the posttraining preserved-LVEF assessment.

Figure 1. Study flow diagram of participant enrollment and assessment completion. EPSS: E-point septal separation; LVEF: left ventricular ejection fraction.



Baseline characteristics are summarized in Table 1. The median age was 30.5 (IQR 28-34) years, and 65% (17/26) were female. Participants included emergency medicine residents (11/26, 42%), interns or general practitioners (8/26, 31%), and board-certified emergency physicians (7/26, 27%). Nearly half of the participants (12/26, 46%) reported no prior experience measuring LVEF, while 38% (10/26) reported occasional

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experience and 15% (4/26) reported regular experience with LVEF assessment.

Table 1. Participant baseline characteristics (N=26).

Characteristics	Values
Age (years), median (IQR)[a]	30.5 (28-34)
Sex, n (%)	
Female	17 (65)
Male	9 (35)
Training status, n (%)	
Emergency physician board certified	7 (27)
Intern/general practitioner	8 (31)
Emergency medicine resident	11 (42)
EF[b] measurement experience, n (%)	
Never	12 (46)
Occasionally	10 (38)
Regularly	4 (15)

[a]IQRs were calculated using R's type 7 sample quantile definition.

[b]EF: ejection fraction.

Pretraining Performance

All 26 participants underwent pretraining assessment. EPSS was successfully completed by all 26 (100%) participants, compared with 25/26 (96.2%) for Teichholz long-axis and 24/26 (92.3%) for Teichholz short-axis. Pretraining absolute LVEF error differed significantly among the 3 methods (*P*=.009), with lower error for EPSS (median 5%, IQR 3-13) than for Teichholz long-axis (17%, IQR 9-27) or Teichholz short-axis (13%, IQR 4-24) in post-hoc comparisons. Measurement time also differed among methods (*P*=.02); EPSS had the shortest median measurement time (73 seconds) and was significantly faster than Teichholz long-axis in post-hoc analysis. Complete pairwise comparisons and effect sizes are provided in Table S8 in Multimedia Appendix 2. Confidence did not differ significantly among methods (*P*=.33; Table 2). Figure 2A shows the distribution of measurement differences.

Before training, physiologically implausible calculated LVEF values below 0% occurred in 1 of 26 EPSS measurements (−87%), 1 of 25 Teichholz long-axis measurements (−157%), and 1 of 24 Teichholz short-axis measurements (−19%). Mean biases were −11.7 (SD 28.5) percentage points for EPSS (95% LoA −67.6 to 44.3), −3.8 (SD 51.5) percentage points for Teichholz long-axis (95% LoA −104.7 to 97.1), and 2.2 (SD 27.6) percentage points for Teichholz short-axis (95% LoA −51.8 to 56.3). Corresponding ICC(2,1) values were 0.136, −0.040, and 0.006, respectively (Table S4 in Multimedia Appendix 2). These extreme observations substantially influenced the pretraining agreement estimates but were retained because they represented measurements actually obtained by participants.

Table 2. Accuracy and confidence in the pretraining period[a].

Outcomes	EPSS[b]	Teichholz long-axis	Teichholz short-axis	*P* value
Absolute LVEF[c] difference from Simpson method, %, median (IQR)	5 (3-13)	17 (9-27), n=25	13 (4-24), n=24	.009
Time to complete measurement, seconds, median (IQR)	73 (53-121)	150 (103-200)	100 (67-184)	.02
Learner confidence score (0-10), median (IQR)	4.5 (2-5)	4 (2-5)	4.5 (2-5)	.33

[a]Values are presented as median (IQR). IQRs were calculated using R's type 7 sample quantile definition and rounded to the nearest whole number where appropriate. Unless otherwise indicated, n=26 for method-specific descriptive statistics. The Friedman test for absolute LVEF difference was based on 23 participants with complete measurements across all 3 methods.

[b]EPSS: E-point septal separation.

[c]LVEF: left ventricular ejection fraction.

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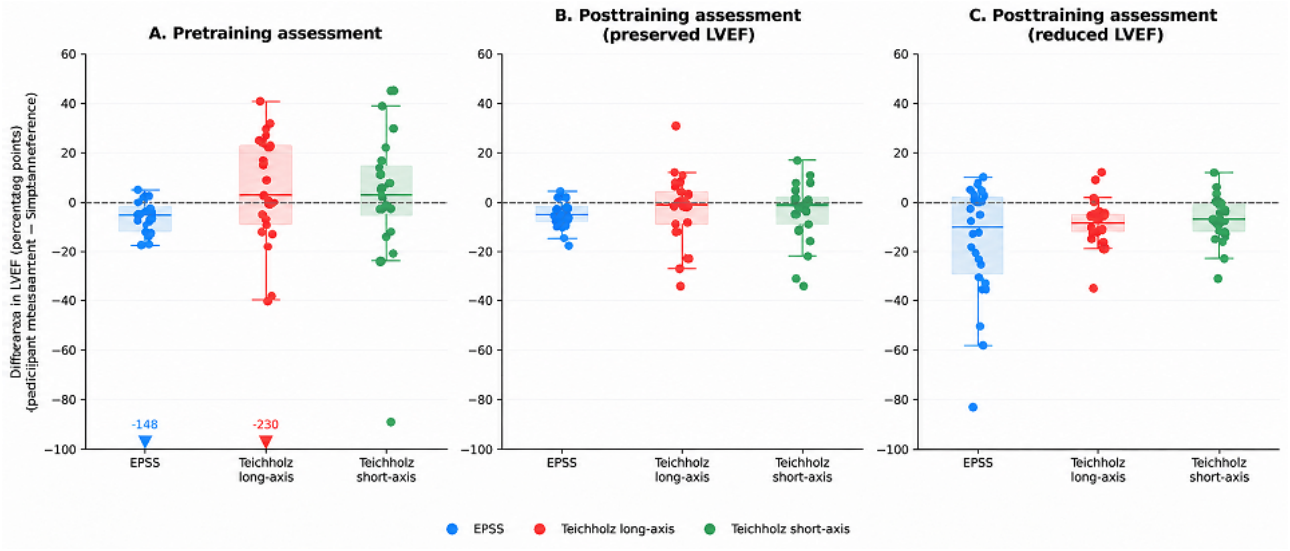
Figure 2. Distribution of differences in left ventricular ejection fraction (LVEF) measurements across methods before and after training. Differences were calculated as participant-measured LVEF minus cardiologist-performed Simpson reference LVEF. The horizontal line at zero represents perfect agreement. A common y-axis scale across panels, and off-scale observations were indicated and retained in all analyses. (A) Pre-training assessment. (B) Post-training assessment in patients with preserved LVEF. (C) Post-training assessment in patients with reduced LVEF.



Posttraining Preserved-LVEF Assessment

As shown in Table 3, the absolute LVEF differences from the Simpson method did not differ significantly among the 3 methods: EPSS (median 5%, IQR 3-8), Teichholz short-axis (median 5%, IQR 2-11), and Teichholz long-axis (median 8%, IQR 2-12), with no statistically significant differences (P=.93).

Table 3. Accuracy and confidence in the posttraining period.[a]

Outcome	EPSS[b]	Teichholz long-axis	Teichholz short-axis	*P* value
Absolute LVEF[c] difference from Simpson method (preserved LVEF), %, median (IQR)	5 (3-8)	8 (2-12)	5 (2-11)	.93
Time to complete measurement (preserved LVEF), seconds, median (IQR)	62 (40-108)	118 (81-164)	105 (84-172)	<.001
Absolute LVEF difference from Simpson method (reduced LVEF), %, median (IQR)	11 (5-29)	11 (5-12)	8 (3-12)	.24
Time to complete measurement (reduced LVEF), seconds, median (IQR)	79 (55-91)	101 (84-153)	119 (87-165)	<.001
Learner confidence score (0-10), median (IQR)	7 (5.3-7)	6 (5-7)	6 (5-7)	.01

[a]Values are presented as median (IQR). IQRs were calculated using R's type 7 sample quantile definition and rounded to the nearest whole number where appropriate. The preserved-LVEF assessment included 25 participants and the reduced LVEF assessment included 26 participants. Friedman tests were based on participants with complete measurements across all three methods. The pooled reduced-LVEF comparison combines measurements from two SPs with reference LVEFs of 16% and 48%, for whom results differed. Case-specific analyses are presented in Table S9 in Multimedia Appendix 2.

[b]EPSS: E-point septal separation.

[c]LVEF: left ventricular ejection fraction.

However, EPSS remained the fastest method, with a median time of 62 seconds, significantly shorter than Teichholz long-axis (118 seconds) and Teichholz short-axis (105 seconds; P<.001). These findings are visually represented in Figure 2B.

In the posttraining preserved-LVEF assessment, EPSS demonstrated a mean bias of −5.3 (SD 5.1) percentage points with 95% LoA from −15.2 to 4.6, compared with −3.0 (SD 13.8; 95% LoA −30.1 to 24.1) for Teichholz long-axis and −4.2 (SD 12; 95% LoA −27.7 to 19.3) for Teichholz short-axis. No statistically significant proportional bias was detected for EPSS (β=−0.25; P=.36), whereas proportional bias was detected for both Teichholz long-axis (β=1.35; P<.001) and Teichholz short-axis (β=1.17; P<.001). The corresponding ICC(2,1) values were 0.248 (95% CI −0.096 to 0.569), 0.145 (95% CI −0.253 to 0.503), and 0.246 (95% CI −0.125 to 0.569), respectively (Table S4 in Multimedia Appendix 2).

Posttraining Reduced-LVEF Assessment

Because the 2 SPs in the reduced-LVEF assessment had substantially different reference LVEFs, method performance was additionally analyzed separately for each SP. Among the 13 participants assessed on the SP with an LVEF of 48%, median absolute LVEF errors were 5 (IQR 2.5-7.5) percentage

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points for EPSS, 6 (IQR 5-12) percentage points for Teichholz long-axis, and 6 (IQR 1-12) percentage points for Teichholz short-axis, with no statistically significant difference among methods (*P*=.48). Among the 13 participants assessed on the SP with an LVEF of 16%, median absolute errors were 30.5 (IQR 20.5–35.5) percentage points for EPSS, 11 (IQR 7-12) percentage points for Teichholz long-axis, and 8 (IQR 5-12) percentage points for Teichholz short-axis. The difference among methods was statistically significant (*P*=.008; Kendall W=0.37). Holm-adjusted post-hoc comparisons demonstrated greater absolute error for EPSS than for Teichholz long-axis (*P*=.035) and Teichholz short-axis (*P*=.01), whereas the two Teichholz methods did not differ significantly (*P*=.36). Detailed case-specific analyses are provided in Table S9 in Multimedia Appendix 2.

During the posttraining reduced-LVEF assessment, calculated LVEF values below 0% occurred in 11 of 26 EPSS measurements and 2 of 26 Teichholz long-axis measurements (−3% and −19%); no negative Teichholz short-axis values occurred. All 11 negative EPSS-derived values occurred in participants assessed on the SP with a reference LVEF of 16%. No calculated LVEF values below 0% occurred with any method during the posttraining preserved-LVEF assessment. All participant-generated values were retained without physiologic truncation or exclusion. Participant-level recorded measurements and corresponding calculated LVEF values are provided in Multimedia Appendix 2.

Although accuracy differed between the two reduced-LVEF SPs, measurement time was analyzed across the pooled reduced-LVEF assessment. EPSS remained the fastest method (median 79 seconds) compared with Teichholz long-axis (101 seconds) and Teichholz short-axis (119 seconds; *P*<.001). The distribution of LVEF measurement errors is shown in Figure 2C. Post-hoc analyses confirmed that EPSS was significantly faster than both Teichholz methods in the preserved- and reduced-LVEF assessments (Table S8 in Multimedia Appendix 2).

Agreement analysis further demonstrated greater variability for EPSS in the reduced-LVEF assessment. EPSS showed a mean bias of −16.0 (SD 23) percentage points with 95% LoA from −61.1 to 29.1 and evidence of proportional bias (*P*<.001); the ICC(2,1) was 0.589. The corresponding mean biases were −8.7 (SD 9.3) percentage points (95% LoA −26.9 to 9.6; ICC=0.806) for Teichholz long-axis and −7.0 (SD 8.9) percentage points (95% LoA −24.4 to 10.5; ICC=0.823) for Teichholz short-axis. Table S4 of Multimedia Appendix 2 provides complete Bland–Altman and agreement analyses for all assessment phases.

Confidence Improvement

Posttraining confidence differed significantly among the 3 methods (*P*=.01), with a median score of 7.0 for EPSS and 6.0 for both Teichholz methods. Post hoc analysis showed higher confidence with EPSS than with Teichholz long-axis (Table S8 in Multimedia Appendix 2).

Exploratory Subgroup and Within-Participant Analyses

Exploratory subgroup analyses showed no statistically significant differences in absolute LVEF error according to training level or prior LVEF measurement experience across the assessment phases (Tables S5 and S6). Pretraining EPSS measurement time differed by training level (*P*=.001). Measurement time also differed by prior LVEF measurement experience for EPSS (*P*=.03) and Teichholz short-axis (*P*=.03) during the posttraining reduced-LVEF assessment. Pretraining confidence differed across the three training-level groups for Teichholz long-axis (Kruskal-Wallis *P*=.015) and Teichholz short-axis (*P*=.009). Median pretraining confidence was lowest among interns/general practitioners (2.5 for both methods), compared with board-certified emergency physicians (3.0 for both methods) and residents (5.0 for both methods). These omnibus tests indicate differences across the three training-level groups and should not be interpreted as pairwise comparisons between specific groups. Reduced-LVEF measurement-error comparisons according to training level and prior LVEF measurement experience were potentially influenced by the distribution of the two reduced-LVEF SPs across participant subgroups. Four of seven board-certified emergency physicians and all four participants who reported regularly measuring LVEF were assessed on the SP with a reference LVEF of 16%, for whom substantially greater EPSS error was observed. Accordingly, differences in reduced-LVEF measurement error across these exploratory subgroups should not be interpreted as effects of training level or prior LVEF measurement experience.

In exploratory within-participant analyses (Table S7 in Multimedia Appendix 2), absolute LVEF error decreased from pretraining to the posttraining reduced-LVEF assessment for Teichholz long-axis (median change +8.0 percentage points, *P*=.03) and Teichholz short-axis (+4.5 percentage points, *P*=.03), whereas the change for EPSS was not statistically significant (median change −4.0 percentage points, *P*=.07). No statistically significant within-participant changes in measurement time were observed. Confidence increased significantly following training for all three methods, with median increases of 2.0 points for EPSS, Teichholz long-axis, and Teichholz short-axis (all *P*<.001).

Discussion

Principal Findings

In this simulation-based study, method performance differed according to the posttraining assessment context. No statistically significant difference in absolute LVEF error was detected among the three methods in the preserved-LVEF assessment or in the SP with an LVEF of 48%. In contrast, EPSS demonstrated substantially greater absolute error than both Teichholz methods in the single SP with an LVEF of 16%. Because each reduced-LVEF severity level was represented by only one SP, this case-specific finding cannot establish a method-by-severity interaction and should be considered hypothesis-generating. However, EPSS was consistently the fastest technique both before and after training. This likely

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reflects its technical simplicity, as EPSS requires only a single linear M-mode measurement in the parasternal long-axis view. This time advantage may reflect the simpler measurement workflow of EPSS, which requires a single linear M-mode measurement in the parasternal long-axis view, whereas Teichholz methods require additional dimensional measurements.

Exploratory within-participant analyses suggested reductions in absolute LVEF error for the Teichholz long-axis and short-axis methods in the reduced-LVEF assessment, while confidence increased for all three methods following training. These exploratory findings demonstrate changes following training in selected measures of quantitative LVEF assessment and learner confidence. However, because different SPs were used across the pretraining and posttraining assessments, observed changes in accuracy and measurement time may reflect both the training intervention and differences in case characteristics and should not be interpreted as isolated causal effects of training.

Previous work has also suggested that EPSS can be obtained by relatively inexperienced emergency physicians [14,18]. Secko et al [18] reported a strong inverse correlation between EPSS measured by junior emergency physicians and visually estimated LVEF by experienced emergency physicians. Importantly, correlation between EPSS and LVEF does not establish the accuracy of converting EPSS into a quantitative LVEF value. Our findings partly align with those of Bahl et al [19], who reported poor agreement of EPSS with reference LVEF estimates and low sensitivity for identifying severe systolic dysfunction. In our study, the substantially greater EPSS error observed in the single SP with an LVEF of 16% similarly raises concern regarding quantitative EPSS performance in severe systolic dysfunction, although the direction of estimation error differed [19]. In contrast, no statistically significant difference among methods was detected in the SP with an LVEF of 48%. Differences in patient population, operator characteristics, study setting, and outcome definitions limit direct comparison between the studies.

Separating the two SPs in the reduced-LVEF assessment revealed substantial heterogeneity that was obscured by the pooled analysis. No statistically significant difference among methods was detected in the SP with an LVEF of 48%, whereas EPSS demonstrated substantially greater absolute error than both Teichholz methods in the SP with an LVEF of 16%. This finding raises the possibility that quantitative EPSS performance may deteriorate at very low LVEF values. However, because the 16% and 48% LVEF assessments each involved only one SP, LVEF severity is inseparable from individual patient characteristics in this dataset. Therefore, these findings cannot establish a method-by-severity interaction and should be considered case-specific and hypothesis-generating.

Physiologically implausible calculated LVEF values were observed with all three methods, particularly before training and in the posttraining assessment of the SP with an LVEF of 16%. These observations substantially influenced some agreement estimates but were retained because they represented actual participant-generated measurements rather than data-entry errors. Such values may reflect clinically relevant measurement failures, including difficulties with image acquisition, M-mode orientation, landmark identification, or caliper placement. During the study sessions, the physician trainers informally observed that some participants had difficulty obtaining an optimal M-mode orientation for EPSS measurement. However, these observations were not collected using a predefined assessment tool or recorded systematically, and image acquisition quality and cursor alignment were not prospectively documented. Therefore, the specific mechanism underlying each extreme value could not be determined.

The greater variability of EPSS in the reduced-LVEF assessment warrants particular attention. Bland-Altman analysis demonstrated a mean bias of −16.0 percentage points and wide 95% LoA (−61.1 to 29.1), together with significant proportional bias. These findings further demonstrate that the absence of a statistically significant difference in absolute error should not be interpreted as evidence of equivalent performance or agreement with the reference method. Therefore, interpret quantitative LVEF derived from EPSS cautiously, particularly at reduced LVEF values. This variability may partly reflect limitations of applying a linear EPSS-to-LVEF conversion equation across the full range of ventricular function. Because EPSS is an anatomic linear measurement rather than a direct volumetric measurement of LVEF, extrapolation of the equation at extreme EPSS values may yield clinically implausible LVEF estimates.

EPSS nevertheless demonstrated a consistent time advantage. In the preserved-LVEF assessment, EPSS required approximately 60 seconds less than the Teichholz methods. In time-sensitive presentations such as undifferentiated shock or acute dyspnea, a measurement that can be obtained approximately one minute faster may facilitate earlier bedside assessment of ventricular systolic function while allowing the clinician to proceed more rapidly to other components of the focused ultrasound examination and resuscitation. This practical advantage should, however, be balanced against the greater measurement variability observed with EPSS in the reduced-LVEF assessment. Thus, the time advantage of EPSS should be weighed against its greater measurement variability and the potential for implausible quantitative LVEF estimates at extreme EPSS values.

Exploratory subgroup analyses did not detect significant differences in absolute LVEF error according to either training level or prior LVEF measurement experience. Prior experience was more consistently associated with self-reported confidence than with measurement accuracy. Reduced-LVEF subgroup comparisons were additionally limited by unbalanced SP allocation across participant subgroups and should not be interpreted as effects of training level or prior LVEF measurement experience. Although several differences in measurement time were observed across subgroups, these findings should be interpreted cautiously because the analyses were exploratory, subgroup sizes were small, particularly for participants who regularly measured LVEF (n=4), and no adjustment for multiple subgroup comparisons was performed. Accordingly, these subgroup findings should be considered exploratory and hypothesis-generating rather than confirmatory.

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Future studies should evaluate these methods in real emergency department patients across a broader spectrum of ventricular function, particularly using multiple patients with severely reduced LVEF.

Strengths and Limitations

A key strength of this study is its pragmatic design, with LVEF measurements performed by front-line physicians of varying experience, reflecting real-world POCUS use. We directly compared three commonly used methods against a reference standard (cardiologist-performed Simpson method) before and after focused training, allowing assessment of both accuracy and changes following training. Additionally, we evaluated time-to-completion and demonstrated that EPSS was significantly faster than Teichholz-based methods, highlighting its practical advantage in emergency and critical care settings.

Several limitations should be acknowledged. First, this was a single-center study with a small sample of physicians and a limited number of SPs, all of whom were adult males, which limits generalizability. Recruitment through the university's Facebook page may also have introduced volunteer or self-selection bias. Second, repeated measurements from the same SPs introduced clustering because participants assigned to the same SP shared the same cardiac anatomy and reference LVEF. This was particularly relevant to the reduced-LVEF assessment, in which 26 participant-level measurements were obtained from only two SPs with reference LVEFs of 16% and 48%. Moreover, each reduced-LVEF level was represented by only one SP. Therefore, the observed case-specific difference cannot distinguish an effect of LVEF severity from individual SP characteristics and should be considered hypothesis-generating. Exploratory subgroup comparisons in the reduced-LVEF assessment were additionally limited by unbalanced SP allocation across participant subgroups. The SP with a reference LVEF of 16% was disproportionately represented in some training-level and prior-experience categories; therefore, observed subgroup differences in measurement error may reflect SP allocation rather than participant characteristics. Third, different SPs were used across assessment phases; consequently, pre- to posttraining changes may reflect both training and differences in case characteristics. Fourth, the linear equation used to derive LVEF from EPSS may produce physiologically implausible estimates at extreme EPSS values, potentially contributing to greater variability in severe systolic dysfunction. Fifth, the agreement analyses were based on a limited range of reference LVEF values represented by the small number of SPs. This is particularly relevant to ICC because ICC estimates are influenced by between-subject variability. The relatively narrow reference LVEF range in the preserved-LVEF assessment (61%-73%) may therefore have reduced ICC estimates despite comparatively narrow absolute LoA. Accordingly, ICC values should be interpreted together with Bland-Altman bias and LoA rather than as standalone measures of method performance. Sixth, measurements were obtained in a controlled simulation setting rather than during real-time clinical care, and the findings may not fully represent performance in acutely ill emergency department patients. Finally, 2 ultrasound systems from the same manufacturer and product family were used, and system assignment was not randomized. Potential inter-system variability, including differences in automated Teichholz calculation, was not assessed separately and may have contributed to measurement variability.

Conclusions

Following focused ultrasound training, no statistically significant difference in absolute LVEF error was detected among methods in the preserved-LVEF assessment or in the SP with an LVEF of 48%. In contrast, EPSS demonstrated greater error than both Teichholz methods in the single SP with an LVEF of 16%. Because each reduced-LVEF severity level was represented by only one SP, this case-specific finding is hypothesis-generating and requires confirmation across multiple patients and a broader spectrum of reduced LVEF. EPSS required less time than the Teichholz methods but demonstrated greater measurement variability in the reduced-LVEF assessment. These findings should not be interpreted as establishing equivalent accuracy among the methods.

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Data Availability

The deidentified analysis dataset and R code used to reproduce the analyses reported in this study are provided as Multimedia Appendix 3.

Generative AI Use

During manuscript preparation and revision, the authors used ChatGPT (OpenAI) solely for language editing, grammar, and clarity. The authors critically reviewed and revised all AI-assisted output. All authors reviewed and approved the final manuscript and take full responsibility for its content.

Authors' Contributions

Conceptualization: TT, Pariwat Phungoen, NHAS

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Methodology: TT, PK, NS, Pariwat Phungoen
Formal analysis: TT, Pariwat Phungoen
Investigation: TT, PK, NS, PS
Data curation: TT
Writing – original draft: TT, Pariwat Phungoen
Writing – review & editing: PK, NS, PS, NHAS, Pariwat Phungoen
Supervision: Pariwat Phungoen, PK
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Conflicts of Interest

None declared.

Multimedia Appendix 1

Training Protocol.
[DOCX File , 30 KB-Multimedia Appendix 1]

Multimedia Appendix 2

Data and analysis.
[DOCX File , 60 KB-Multimedia Appendix 2]

Multimedia Appendix 3

R Analysis Script.
[DOCX File , 30 KB-Multimedia Appendix 3]

Multimedia Appendix 4

STARD 2015 checklist.
[PDF File (Adobe PDF File), 325 KB-Multimedia Appendix 4]

Multimedia Appendix 5

TIDieR checklist.
[PDF File (Adobe PDF File), 336 KB-Multimedia Appendix 5]

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Abbreviations

EPSS: E-point septal separation
ICC: intraclass correlation coefficient
LoA: limits of agreements
LVEF: left ventricular ejection fraction
POCUS: point-of-care ultrasound
SP: standardized patient
STARD: Standards for Reporting Diagnostic Accuracy Studies
TCTR: Thai Clinical Trials Registry
TIDieR: Template for Intervention Description and Replication

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