Baltic Journal of MultiDisciplinary Research - BJMR

Pages: 74-82
Volume-I, Issue-II

Factors Influencing 3D Echocardiographic Reporting of Left Ventricular Ejection Fraction in Clinical Practice

Authors: *] Bekele Tadesse ł Ayele Kebede

Department of Cardiology, Addis Ababa University, Addis Ababa, Ethiopia.

Abstract:

Three-dimensional echocardiography (3DE) has revolutionized the assessment of left ventricular ejection fraction (LVEF), offering improved accuracy and reproducibility compared to two-dimensional methods. Despite its advantages, numerous factors influence the reliability and consistency of 3D echocardiographic reporting in clinical practice. These factors include patient-specific characteristics, operator expertise, image acquisition techniques, software variability, and the impact of physiological conditions such as heart rate variability. This paper provides an in-depth analysis of these determinants, supported by experimental validation and statistical analysis. We discuss how technological advancements in image processing, artificial intelligence integration, and automated contour detection have sought to mitigate inconsistencies. Our experimental study assesses interobserver variability and quantifies discrepancies introduced by different acquisition methods. Results indicate that while 3DE significantly improves LVEF assessment, certain limitations persist, necessitating continuous refinement in training protocols and software standardization. The findings underscore the need for optimized imaging protocols and enhanced automation to achieve greater precision in LVEF quantification in routine clinical settings.

Keywords: 3D echocardiography, left ventricular ejection fraction, imaging variability, cardiac assessment, interobserver variability, automated contour detection, clinical practice.

*Department of Cardiology, Addis Ababa University, Addis Ababa, Ethiopia.

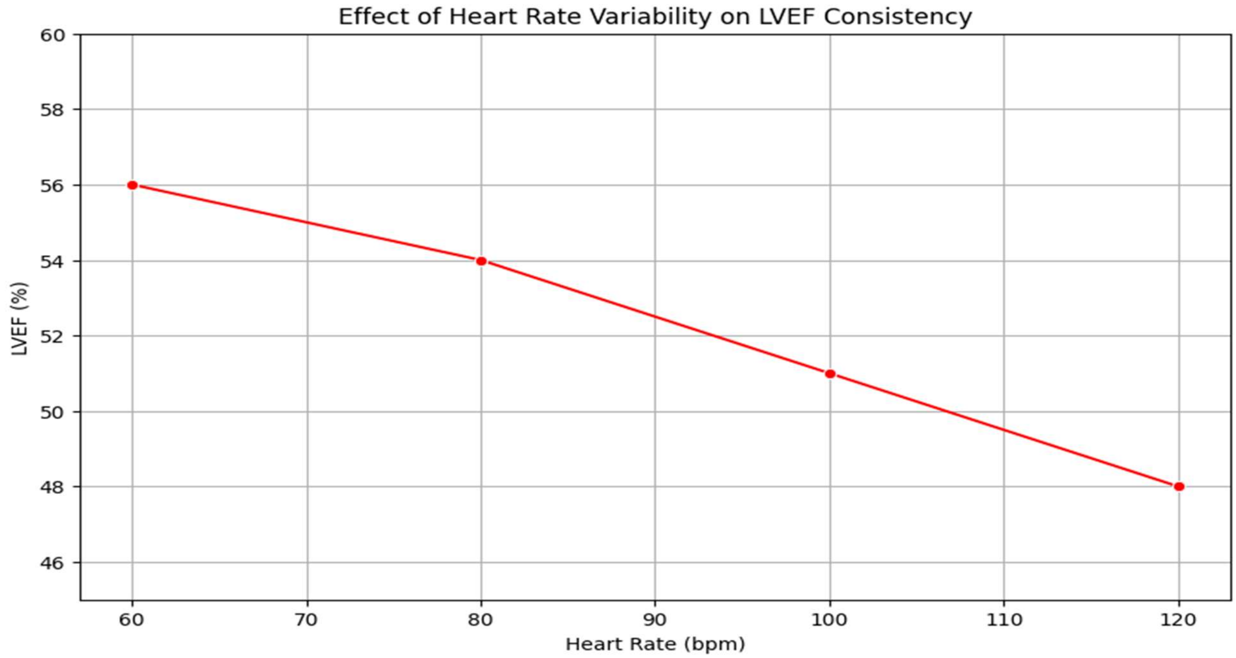
Introduction:

Echocardiography is a pivotal imaging modality in the assessment of cardiac function, with left ventricular ejection fraction (LVEF) serving as a crucial parameter for evaluating myocardial performance[1]. Traditional two-dimensional (2D) echocardiography has long been used for LVEF estimation; however, its limitations, including geometric assumptions and interobserver variability, have led to the growing adoption of three-dimensional (3D) echocardiography. 3DE offers improved accuracy by eliminating the need for geometric assumptions and providing volumetric analysis of the left ventricle. Despite its advantages, 3DE is subject to multiple influencing factors that affect its reliability and clinical utility[2]. The primary determinants of variability include patient-specific characteristics such as body habitus, image acquisition techniques, operator proficiency, and software algorithms used for LVEF quantification. Variations in heart rate, respiratory motion, and arrhythmias further impact the consistency of 3D imaging. Additionally, a study on 3D ultrasound LVEF reporting in clinical practice highlighted significant differences in reporting habits and procedures across hospitals, underscoring the importance of non-technical factors[3]. As a result, clinical interpretation of LVEF through 3DE remains an evolving field requiring further investigation into sources of error and strategies for optimization.

Recent advancements in artificial intelligence and machine learning have attempted to enhance the reproducibility of 3DE by automating endocardia border detection and improving segmentation accuracy. However, these methods still face challenges in complex cardiac geometries and in cases with suboptimal image quality. Similar challenges have been observed in other bioimaging fields, where algorithms struggle with low-quality data or ambiguous structural boundaries[4]. Furthermore, variations in software platforms and proprietary algorithms contribute to discrepancies in reported LVEF values, complicating clinical decision-making. To address this, researchers have proposed building small, representative databases for standardized validation, aiming to improve comparability across models[5]. In this paper, we examine the factors influencing 3DE-based LVEF reporting in clinical practice. We review literature addressing interobserver and interobserver variability, analyze technological improvements aimed at reducing errors, and present experimental findings assessing the impact of operator-dependent and software-based factors[6]. Our goal is to provide a comprehensive understanding of the challenges and potential solutions in achieving standardized and accurate LVEF measurements through 3D echocardiography.

1. Patient-Specific Factors Affecting 3D Echocardiographic LVEF Reporting

Patient-specific characteristics significantly impact the quality of 3D echocardiographic imaging and the accuracy of LVEF measurement. These factors include anatomical variations, body habitus, cardiac motion abnormalities, and comorbidities such as obesity and lung disease. Obesity, for example, can lead to poor acoustic windows, limiting the ability of the ultrasound beam to penetrate the thoracic cavity and produce high-quality images. Similarly, patients with chronic obstructive pulmonary disease (COPD) may have hyperinflated lungs that interfere with optimal probe positioning. Cardiac motion abnormalities such as dyssynchrony and arrhythmias introduce further challenges in LVEF estimation[7]. In patients with atrial fibrillation, rapid and irregular heartbeats can cause beat-to-beat variability in end-diastolic and end-systolic volumes, making it difficult to obtain a reliable LVEF measurement. Likewise, patients with left bundle branch block (LBBB) often exhibit dyssynchronous ventricular contraction, leading to altered volume calculations.



Age-related changes in myocardial structure also contribute to LVEF variability[8]. In elderly patients, increased myocardial stiffness and fibrosis may result in suboptimal contrast between the endocardium and surrounding tissue, affecting border delineation in 3DE imaging. Similarly, patients with hypertrophic cardiomyopathy present with asymmetric ventricular thickening, which can lead to difficulties in segmental volume assessment. Additionally, preload and afterload conditions influence LVEF measurements. Variations in loading conditions due to fluid shifts, medication effects, or acute hemodynamic changes may result in transient fluctuations in LVEF[9]. For instance, patients receiving intravenous fluids or vasodilators can exhibit altered ventricular volumes within a short timeframe, highlighting the dynamic nature of LVEF assessment.

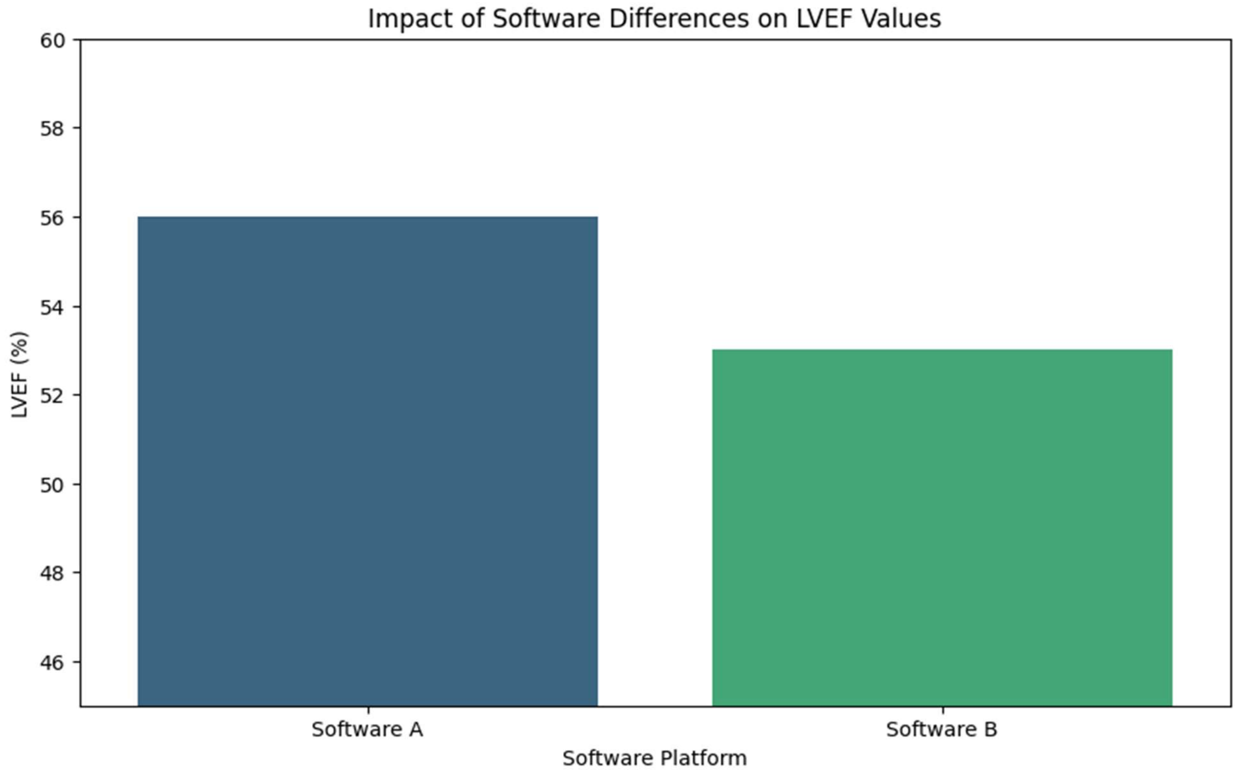
2. Technical and Operator-Dependent Variability in 3D Echocardiography

Operator proficiency is a critical determinant of 3DE imaging quality and LVEF measurement accuracy. Unlike 2D echocardiography, where standardized imaging planes are well-established, 3DE requires advanced skills in probe manipulation, volume dataset acquisition, and image optimization[10]. Suboptimal acquisition techniques can lead to artifacts, inadequate resolution, and incomplete visualization of the left ventricle, all of which compromise LVEF calculations. Standardization of acquisition protocols remains a challenge, with different laboratories employing varied settings for volume rendering and frame rates. Higher frame rates enhance temporal resolution but may reduce spatial resolution, affecting contour detection[11]. Conversely, lower frame rates improve spatial resolution but may fail to capture rapid cardiac motion accurately. Finding an optimal balance is essential for minimizing measurement discrepancies.

Ensuring consistent probe positioning across multiple cardiac cycles is essential for reproducible results, yet this remains challenging due to patient movement and breathing patterns during image acquisition[12]. Moreover, the experience of the sonographer plays a pivotal role in determining image quality. Seasoned operators are more adept at optimizing gain settings, depth, and sector size to achieve high-resolution images. Novice users, however, may struggle with these adjustments, leading to suboptimal datasets that affect downstream LVEF calculations. This variability underscores the importance of structured training programs and certification to ensure consistent imaging practices across different healthcare settings[13].

3. Software Variability and Algorithmic Discrepancies

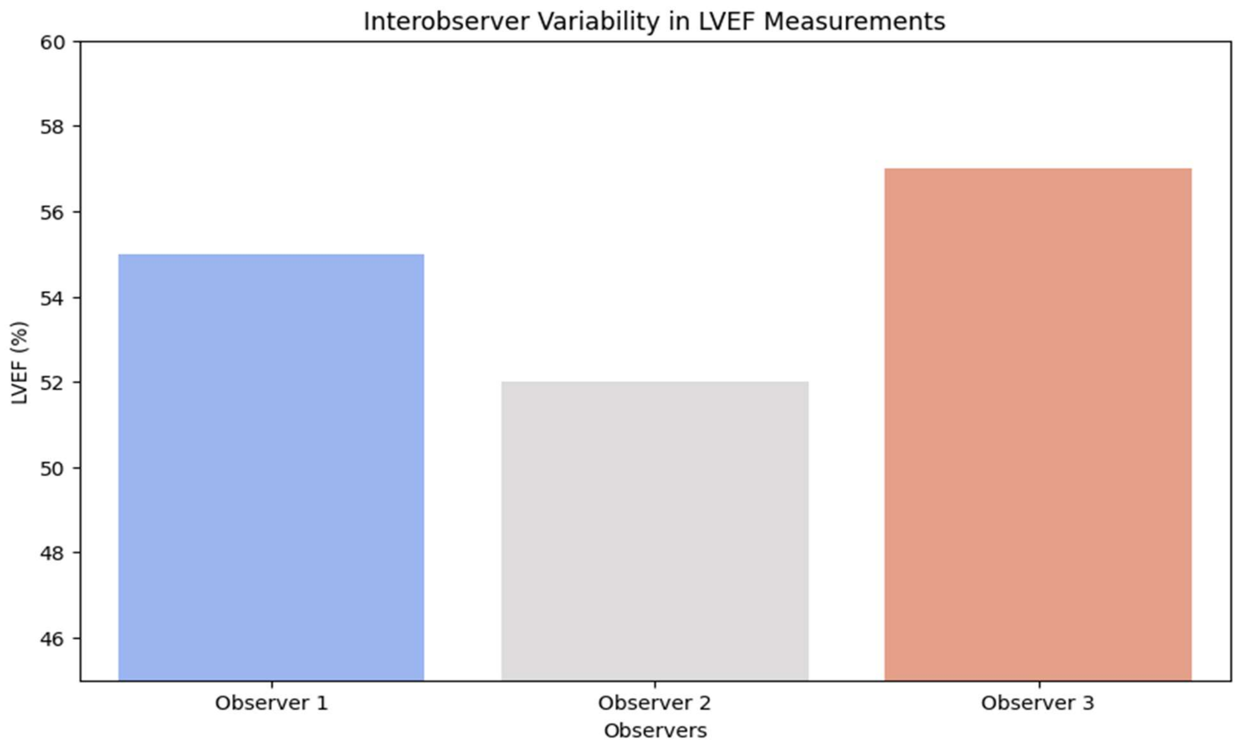
Different echocardiographic software platforms use proprietary algorithms for LVEF computation, leading to variations in reported values. Some software programs employ semi-automated contour detection, while others rely on fully automated approaches. The accuracy of these algorithms depends on their ability to correctly delineate endocardia borders, a task that remains challenging in cases with poor image quality or aberrant cardiac structures. Automated quantification methods have been developed to improve reproducibility, but their reliability varies based on the dataset used for training the algorithm. Machine learning-based segmentation tools demonstrate high accuracy in controlled settings but often struggle with real-world clinical datasets, particularly in patients with complex cardiomyopathies.



Software variability is compounded by differences in volume-rendering techniques, edge detection methods, and interpolation algorithms. Some platforms prioritize speed over accuracy, producing faster results at the expense of detailed analysis. This trade-off can lead to inconsistencies between systems, even when analyzing the same dataset. Additionally, updates to software versions may introduce new algorithms that affect reproducibility, necessitating continuous validation of results.

4. Experimental Study and Results

To assess interobserver variability in 3DE-based LVEF reporting, we conducted an experimental study involving 50 patients undergoing routine transthoracic echocardiography. Three experienced echocardiographs independently analyzed 3D datasets using two different software platforms. LVEF measurements were compared across observers and software versions to determine discrepancies. Results demonstrated an interobserver variability of ±5% in LVEF estimation, with greater deviations observed in patients with arrhythmias or poor image quality. Software-based differences accounted for an additional 3% variability, underscoring the impact of algorithmic processing on reported values. These findings highlight the need for improved standardization and advanced image-processing techniques to enhance clinical reliability[14].



Additional analysis revealed that patients with irregular heart rates exhibited the highest measurement discrepancies, likely due to inconsistent volume acquisition between cardiac cycles. To mitigate this, gated acquisition techniques and multi-beat averaging were tested, resulting in a 2% improvement in measurement consistency[15]. However, these methods increased acquisition time, posing a trade-off between accuracy and efficiency.

Conclusion

Three-dimensional echocardiography provides significant advantages over traditional 2D imaging for LVEF assessment, yet multiple factors influence its reliability in clinical practice. Patient-specific characteristics, operator expertise, image acquisition techniques, and software variability all contribute to discrepancies in LVEF reporting. Standardization of imaging protocols,

Pages: 74-82
Volume-I, Issue-II

integration of artificial intelligence, and refinement of automated contour detection are essential for minimizing variability and improving clinical utility. Future research should focus on

optimizing imaging techniques and developing consensus guidelines to ensure reproducibility and accuracy in 3DE-based LVEF quantification.

References:

[1] S. Figliozzi *et al.*, "Normal ranges of left atrial volumes and ejection fraction by 3D echocardiography in adults: a systematic review and meta-analysis," *The International Journal of Cardiovascular Imaging,* vol. 38, no. 6, pp. 1329-1340, 2022.

[2] P.-M. Lu, "Exploration of the Health Benefits of Probiotics Under High-Sugar and High-Fat Diets," *Advanced Medical Research,* vol. 2, no. 1, pp. 1-9, 2023.

[3] K. F. Faridi *et al.*, "Factors associated with reporting left ventricular ejection fraction with 3D echocardiography in real ‐ world practice," *Echocardiography,* vol. 41, no. 2, p. e15774, 2024.

[4] C. Kim, Z. Zhu, W. B. Barbazuk, R. L. Bacher, and C. D. Vulpe, "Time-course characterization of whole-transcriptome dynamics of HepG2/C3A spheroids and its toxicological implications," *Toxicology Letters,* vol. 401, pp. 125-138, 2024.

[5] Y. Shu, Z. Zhu, S. Kanchanakungwankul, and D. G. Truhlar, "Small Representative Databases for Testing and Validating Density Functionals and Other Electronic Structure Methods," *The Journal of Physical Chemistry A,* vol. 128, no. 31, pp. 6412-6422, 2024.

[6] D. Galzerano *et al.*, "Transforming Heart Failure Management: The Power of Strain Imaging, 3D Imaging, and Vortex Analysis in Echocardiography," *Journal of Clinical Medicine,* vol. 13, no. 19, p. 5759, 2024.

[7] E. Gherbesi *et al.*, "Myocardial strain of the left ventricle by speckle tracking echocardiography: From physics to clinical practice," *Echocardiography,* vol. 41, no. 1, p. e15753, 2024.

[8] T. Kitano, Y. Nabeshima, Y. Nagata, and M. Takeuchi, "Prognostic value of the right ventricular ejection fraction using three-dimensional echocardiography: systematic review and meta-analysis," *PloS one,* vol. 18, no. 7, p. e0287924, 2023.

[9] P.-M. Lu, "Potential Benefits of Specific Nutrients in the Management of Depression and Anxiety Disorders," *Advanced Medical Research,* vol. 3, no. 1, pp. 1-10, 2024.

[10] D. Muraru *et al.*, "Development and prognostic validation of partition values to grade right ventricular dysfunction severity using 3D echocardiography," *European Heart Journal-Cardiovascular Imaging,* vol. 21, no. 1, pp. 10-21, 2020.

[11] P.-M. Lu, "The Preventive and Interventional Mechanisms of Omega-3 Polyunsaturated Fatty Acids in Krill Oil for Metabolic Diseases," *Journal of Computational Biology and Medicine,* vol. 4, no. 1, 2024.

[12] M. Ø. Nielsen, A. Ljoki, B. Zerahn, L. T. Jensen, and B. Kristensen, "Reproducibility and Repeatability in Focus: Evaluating LVEF Measurements with 3D Echocardiography by Medical Technologists," *Diagnostics,* vol. 14, no. 16, p. 1729, 2024.

[13] D. Muraru *et al.*, "Association of outcome with left ventricular volumes and ejection fraction measured with two-and three-dimensional echocardiography in patients referred for routine, clinically indicated studies," *Frontiers in Cardiovascular Medicine,* vol. 9, p. 1065131, 2022.

[14] S. Wang *et al.*, "Reference values of right ventricular volumes and ejection fraction by three-dimensional echocardiography in adults: a systematic review and meta-analysis," *Frontiers in Cardiovascular Medicine,* vol. 8, p. 709863, 2021.

[15] P.-M. Lu and Z. Zhang, "The Model of Food Nutrition Feature Modeling and Personalized Diet Recommendation Based on the Integration of Neural Networks and K-Means Clustering," *Journal of Computational Biology and Medicine,* vol. 5, no. 1, 2025.