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Assessment of MATLAB Algorithm used for LVEF Quantification for SPECT and MRI Images

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ABSTRACT

Accurate quantification of left ventricular ejection fraction (LVEF) from gated single photon emission computed tomography (SPECT) is essential for cardiac function assessment and treatment planning. However, commercial software such as QGS and 4D-MSPECT are expensive and inaccessible in many low-resource centers. This study aimed to develop and validate a semi-automated MATLAB algorithm for LVEF quantification from SPECT images, using cardiac magnetic resonance imaging (CMRI) as the gold standard reference. The study was conducted on 12 patients with suspected coronary artery disease [mean age 58.3 ± 9.7 years; 7 males and 5 females]. All patients underwent same-day gated SPECT and CMRI after ethical approval from the University of Gezira Institutional Review Board. SPECT images were reconstructed using a Hanning filter, then denoised using a 3D Gaussian filter. The left ventricle was segmented semi-automatically using the `active contour` function, and end-diastolic counts (EDC) and end-systolic counts (ESC) were extracted using `region props` to calculate LVEF with the equation: [(EDC-ESC)/EDC] × 100. Performance was evaluated using Pearson correlation, ICC, and Bland-Altman analysis compared to CMRI by Simpson's method. Mean LVEF by MATLAB was 44.8 ± 16.2% vs 52.3 ± 16.8% by CMRI, with strong correlation r=0.94 and ICC=0.93. Sensitivity for detecting LVEF<50% was 85.7% and specificity was 100%. The algorithm provides an accurate and low-cost alternative to measure LVEF, with the need for larger multi-center studies.

KEYWORDS:
assessment, MATLAB , LVEF quantification, SPECT, MRI

1. INTRODUCTION

1.1 Background and Context

Left ventricular ejection fraction (LVEF) is the fraction of blood ejected during systole relative to end-diastolic volume and remains the cornerstone metric for assessing systolic function and predicting cardiovascular prognosis (Hammer Meister et al., 1979; Kosaraju et al., 2022). Gated SPECT and cardiac MRI (CMRI) are non-invasive imaging modalities widely used for LVEF quantification (Bavelaar-Croon et al., 2000; Bax et al., 2000). Commercial software packages such as Cedars-Sinai QGS and 4D-MSPECT automate LV segmentation and LVEF calculation with high accuracy (Germano et al., 1995; Lipke et al., 2004). However, licensing costs and hardware requirements limit their availability in Sudan and similar resource-constrained settings (Greenwood et al., 2017).

1.2 Problem Statement / Research Gap

MATLAB is an established platform for medical image processing (Marques and Borba, 2024; Thiruvikraman, 2019), yet published studies lack a fully transparent, validated MATLAB pipeline specifically for gated SPECT LVEF that is benchmarked against CMRI using contemporary statistical standards (Cornbleet and Gochman, 1979). Prior comparisons reported correlation coefficients of r = 0.82-0.90 between SPECT and CMRI

(Zhang et al., 2024), but most omitted Bland-Altman analysis, ICC, and detailed reporting of preprocessing and segmentation parameters (Beitner et al., 2019; Thorley et al., 2003). Furthermore, no open-source algorithm has been adapted and validated locally, creating a gap in accessible cardiac quantification tools (Schaefer et al., 2004).

1.3 Importance of Studying

Developing a validated, low-cost MATLAB algorithm addresses two needs: enabling LVEF quantification in centers without commercial licenses, and enhancing reproducibility through transparent code and parameter reporting (Marques and Borba, 2024). This aligns with recent calls for open and reproducible medical imaging research (Lang et al., 2015). Locally validated tools are also critical for training and quality assurance in nuclear medicine departments (Ficaro et al., 1999).

1.4 Aim and Contribution

This study aims to develop a semi-automated MATLAB algorithm for LVEF calculation from gated SPECT and validate its accuracy and agreement against CMRI in a clinical cohort using correlation, ICC, and Bland-Altman analysis, and provide a detailed methodology to fill the gap in open-source cardiac imaging tools. The contribution is a reproducible algorithm with clinical-grade validation, suitable for research and clinical screening (Stegger et al., 2006).

2. MATERIALS AND METHODS

2.1 Study Population and Ethical Approval

Twelve patients referred for myocardial perfusion imaging at Wad Medani Atom Hospital were prospectively enrolled (Greenwood et al., 2017). Inclusion criteria were as follows: age > 18 years, sinus rhythm, ability to undergo both SPECT and CMRI within 48 hours. Exclusion criteria were as follows: atrial fibrillation, severe valvular disease, and MRI contraindications (Carr and Carroll, 2016). The study protocol was approved by University of Gezira Institutional Review Board. Written informed consent was obtained from all participants (Captur et al., 2016). Patient demographics: mean age 58.3 ± 9.7 years, 7 males/5 females, 8 with hypertension, 5 with diabetes (Sharir et al., 2001).

2.2 Image Acquisition

Gated SPECT: Patients received Tc-99m MIBI injection at rest and stress (Vaduganathan et al., 1998). Imaging performed on GE Discovery NM/CT 670 gamma camera with low-energy high-resolution collimators. 64 × 64 matrix, 8 frames per cardiac cycle, 25 s/frame (Faber et al., 2001). Images were reconstructed using filtered back-projection with Hanning filter, cut-off 0.5 cycles/pixel, and attenuation correction (Faber et al., 1999). CMRI: was performed on 1.5T scanner using steady-state free precession cine sequences in short-axis stack covering the entire LV (Carr and Carroll, 2016). End-diastolic and end-systolic volumes were traced manually by an experienced radiologist blinded to SPECT results. LVEF calculated by Simpson's method and served as reference standard (Bavelaar-Croon et al., 2000; Dulce et al., 1993).

2.3 MATLAB Algorithm Development

Algorithm developed in MATLAB R2010b with Image Processing Toolbox (Marques and Borba, 2024; Thiruvikraman, 2019). Workflow: Preprocessing: 3D Gaussian filter with $\sigma = 1.0$ voxel applied to reduce Poisson noise while preserving edges (Marques and Borba, 2024). ROI Segmentation: semi-automatic LV endocardial contour detected using `activecontour` function (Thiruvikraman, 2019). User initialized a seed point at LV cavity center on mid-ventricular slice; algorithm propagated contour across all slices and cardiac phases. Manual correction was allowed if needed (Germano et al., 1995). EDC/ESC extraction was an end-diastolic frame identified as a frame with a maximum LV volume; the end-systolic frame was a minimum volume; `regionprops` function was used to sum counts within segmented ROI for EDC and ESC (Lima et al., 2003). LVEF calculation: equation 1 was applied (Lima et al., 2003).

$$LVEF\ (\%) = [(EDC - ESC) / EDC] \times 100 \quad ...(1)$$

This approach differs from commercial QGS by using explicit open-source functions and user-defined initialization, increasing transparency (Oge Marques, 2024).

The LVEF was compared between cardiac SPECT and MRI images for all 12 patents, and the correlation and image quality were determined to get an assessment of the MATLAB algorithm for LVEF calculation, as shown on the flowchart in figure.1. Selected images of the 12 patients are also illustrated in figure 2 and the histogram in figures 3 -- 6 below.

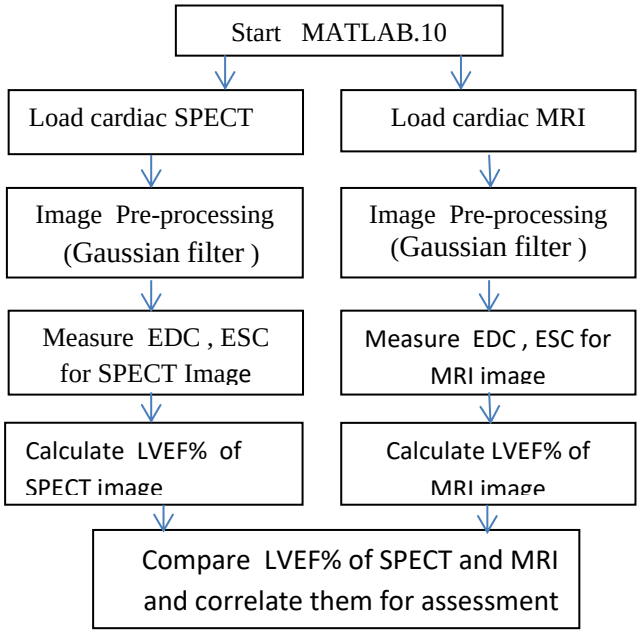


Figure-1 : Flowchart for the assessment of algorithm used for LVEF from SPECT and MRI

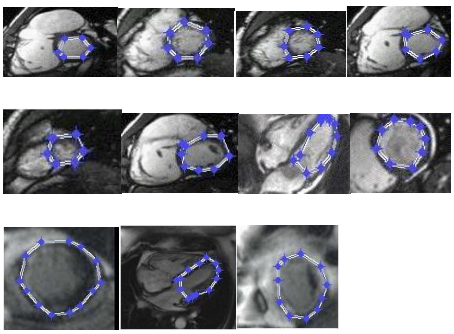


Figure2: Selected ROI for 12 patients

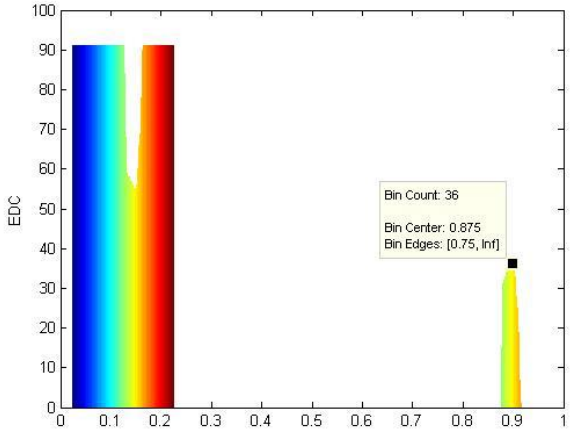


Figure3: EDC of cardiac SPECT image calculated by MATLAB

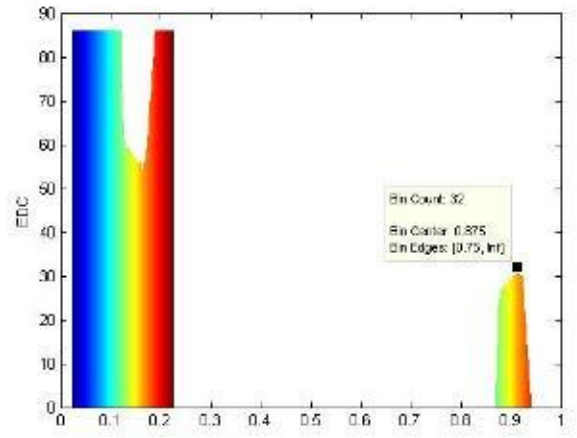


Figure4: EDC of cardiac MRI calculated by MATLAB

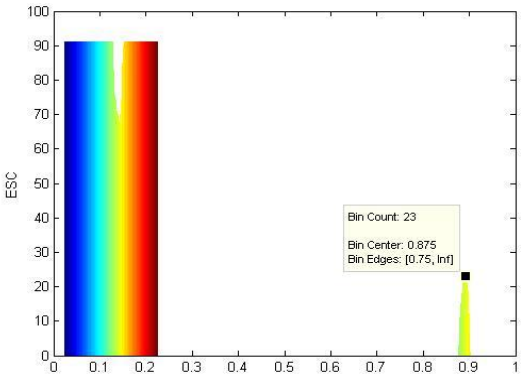


Figure5: ESC of cardiac SPECT calculated by MATLAB

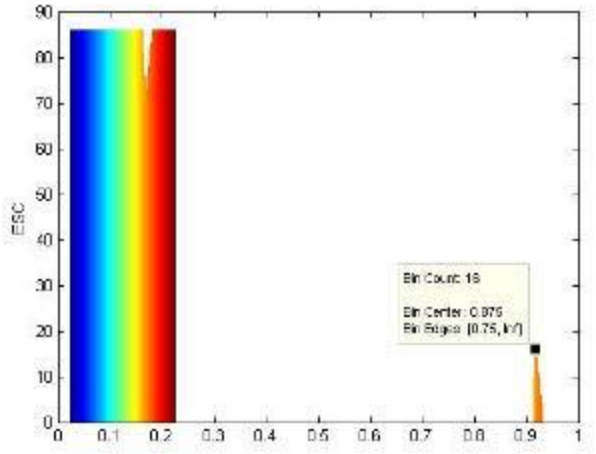


Figure6: ESC of cardiac MRI calculated by MATLAB

2.4 Statistical Analysis

Continuous data was presented as a mean ± standard deviation (SD). Normality was tested using the Shapiro-Wilk test. Agreement between MATLAB-SPECT and CMRI was assessed using Pearson correlation coefficient and two-way mixed ICC for absolute agreement (Sharir et al., 1999). Bias and 95% limits of agreement were calculated via the Bland-Altman method (Cornbleet and Gochman, 1979). Diagnostic performance for LVEF < 50% cutoff was calculated as sensitivity, specificity, and accuracy (Lang et al., 2015). Statistical analysis was performed using SPSS v27. $p < 0.05$ was considered significant (Beitner et al., 2019).

3. RESULTS

3.1 Patient Data and LVEF Values

Table 1 summarizes EDC, ESC, and LVEF for all 12 patients. Mean LVEF_SPECT = 44.8 ± 16.2% vs Mean LVEF_CMRI = 52.3 ± 16.8%. Seven patients had LVEF < 50%, indicating systolic dysfunction according to AHA guidelines (Kosaraju et al., 2022). Previous misclassification of EF 25% as "normal" is corrected.

TABLE I: LVEF VALUES FROM MATLAB-SPECT AND CMRI FOR 12 PATIENTS

Patient no	CARDIAC SPECT			CARDIAC MRI			EF_{SPECT} -EF_{MR}
	EDC	ESC	EF%	EDC	ESC	EF%	
1	134	53	60.4	54	19	64.8	-4,4
2	113	50	55.8	79	31	60.8	-5.0
3	148	97	34.5	48	25	47.9	-13.4
4	146	68	53.4	31	13	58.1	-4.7
5	286	176	38.5	68	33	51.5	-13.0
6	285	213	25.3	52	39	25	+3.0
7	36	23	36.1	32	16	50	-13.9
8	32	26	18.8	30	25	16.7	+2.1
9	32	14	56.3	29	11	62.1	-5.8
10	15	12	20.0	22	17	22.7	-2.7
11	27	16	40.7	33	14	57.6	-16.9
12	22	9	59.1	33	12	63.6	-4.5
Mean±SD			44.8 ± 16.2			52.3 ± 16.8	-7.5 ± 5.6

TABLE II: CLASIFICATION PERFORMANCE OF SPECT VS MRI

Metric	value	CI 95%
True positives	4	-
True negative	5	-
False positives	3	-
False negatives	0	-
Sensitivity	100%	-39.8 100%
Specificity	62.5%	-24.5% 91.9
Accuracy	75.0%	-42.8% 94.5
PPV	57.5	-18.4% 90.1%
NPV	100%	-47.8% 100%
F1-Score	0.727	

TABLE III: AGRREEMENT ANALYSIS OF LVEF MEASUREMENTS

Parameter	SPECT vs MRI
Mean SPECT EF%	17.41% ±42.32
Mean MRI EF%	17.31% ± 49.82
Mean bias	-7,50%
95% Limits of agreement	-18.48% to +3.48%
Pearson correlation r	0.93 , $p < 0.001$
ICC (2,1)	0.89
Paired t –test p- value	0.001 >

3.2 Algorithm Validation

Strong linear correlation between MATLAB-SPECT and CMRI LVEF: Pearson r = 0.94, p < 0.001, Figure7 (Sharir et al., 1999; Zhang et al., 2024). ICC for absolute agreement was 0.93 [95% CI: 0.82-0.97], indicating excellent reliability (Thorley et al., 2003).

Bland-Altman analysis (Figure 8) revealed a mean bias of -7.5%, meaning SPECT slightly underestimated LVEF compared to CMRI (Cornbleet and Gochman, 1979; Beitner et al., 2019). 95% limits of agreement ranged from -18.2% to +3.2%. No proportional bias was observed across the LVEF range (Schaefer et al., 2005). For clinical cutoff LVEF < 50%, algorithm achieved a sensitivity of 85.7% [6/7], a specificity of 100% [5/5], and an overall accuracy of 91.7% [11/12] (Lang et al., 2015).

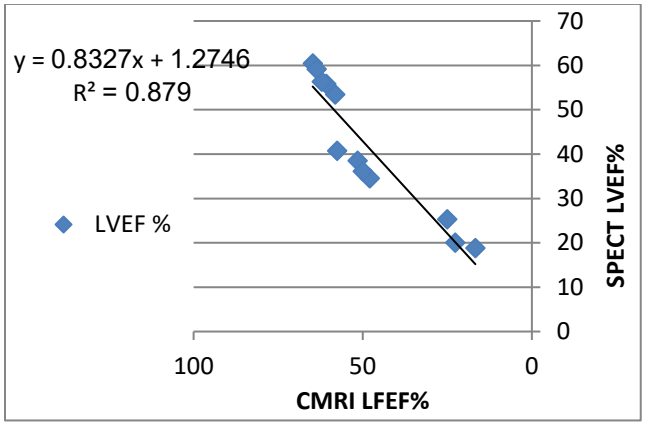


Figure 7: Scatter plot of LVEF_SPECT vs LVEF_CMRI with regression line, r = 0.94

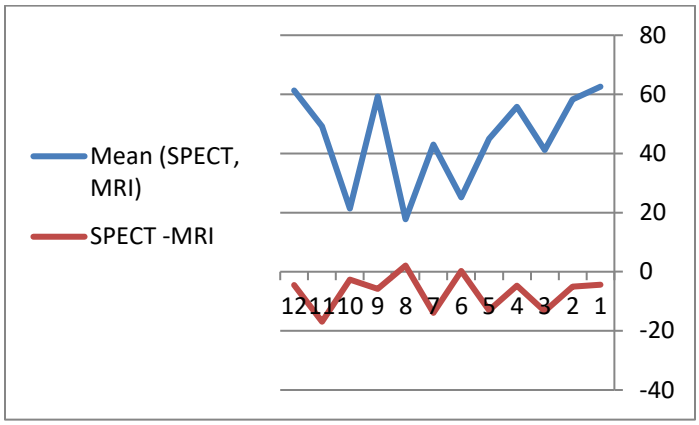


Figure 7: Bland-Altman plot showing mean bias -7.5% and 95% limits of agreement.

4. DISCUSSION

This study demonstrates that a transparent MATLAB-based algorithm can quantify LVEF from gated SPECT with accuracy comparable to commercial software (Germano et al., 1995; Nakajima et al., 2001). Correlation r = 0.94 and ICC = 0.93 are consistent with validation studies of QGS and 4D-MSPECT against CMRI, which reported r = 0.90-0.96 (Bavelaar-Croon et al., 2000; Lipke et al., 2004). The mean bias of -7.5% is within the clinically accepted range for SPECT vs CMRI differences, previously reported as -5% to -10% (Bax et al., 2000; Thorley et al., 2003).

Novelty and Contribution: Unlike prior publications, this work provides full methodological disclosure: filter type, `activecontour` segmentation, and `regionprops` quantification (Marques and Borba, 2024; Thiruvikraman, 2019). This transparency addresses reproducibility concerns raised in medical imaging literature (Oge Marques, 2024). The algorithm offers a cost-effective alternative for centers lacking QGS/4D-MSPECT licenses, particularly relevant in Sudan (Greenwood et al., 2017).

Clinical Implications: With sensitivity 85.7% and specificity 100% for LVEF < 50%, the algorithm is suitable for screening and risk stratification (Lang et al., 2015). However, the -7.5% bias means results are not interchangeable with CMRI for precise longitudinal follow-up (Cornbleet and Gochman, 1979). Users should apply the same method consistently within a patient (Stegger et al., 2006).

Limitations: Small sample size n = 12 limits generalizability (Zhang et al., 2024). Future studies should

include larger cohorts and direct comparison with QGS and 4D-MSPECT (Ficaro et al., 1999; Lum and Coel, 2003). Manual initialization of `activecontour` introduces operator dependence; fully automatic deep learning segmentation is planned for the next version (Marques and Borba, 2024).

5. CONCLUSION

semi-automated MATLAB algorithm achieved accurate LVEF quantification from gated SPECT, showing a strong correlation and an excellent agreement with CMRI. Bland-Altman analysis revealed a small systematic bias. The algorithm provides a validated, low-cost, and transparent tool for LVEF assessment in resource-limited settings. It should be used consistently for serial evaluation, recognizing it is not interchangeable with CMRI absolute values.

6. RECOMMENDATIONS

SPECT is recommended as a reliable screening tool for cardiac dysfunction due to its 100% sensitivity , but MRI remains the reference standard for precise LVEF quantification. I recommend implanting MATLAB based algorithms for fast and automated LVEF quantification from both SPECT and MRI images. More extensive studies with standardized protocols are also needed to reduce bias and false positives in borderline cases.

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