Reproducibility of parameters assessing right ventricular systolic function in patients after an acute myocardial infarction

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Abstract

Purpose: To assess reproducibility of 2D echocardiography parameters of right ventricular systolic function, such as tricuspid annular plane systolic excursion, right ventricular systolic wave velocity, fractional area change, and 3D right ventricular ejection fraction, through measurements performed by operators with different levels of experience, in patients with acute myocardial infarction.

Methods: Measurements were performed offline, independently, by three echocardiographers with different levels of experience: Reader 1 – advanced (5 years of training in 2DE, 3 years in 3DE); Reader 2 – intermediate (3 years of training in 2DE, 1 year in 3DE); Reader 3 – beginner (1 year of training in 2DE, 3 months in 3DE). Interobserver variability and agreement between readers were compared using Bland-Altman plots, as bias and limits of agreement (LOA), Pearson correlations and intraclass correlation coefficients.

Results: 63 patients (52 males, 56.8±10.3 years) were analysed. All measurements showed excellent interobserver variability and agreement. Bias values were low, and LOA intervals were narrow, across all assessed parameters. Generally, bias values were lower between the advanced and intermediate readers with the exception of FAC: R1 vs R2 – bias 0.36, LOA -4.9;5.62 ($r=0.96$, $p<0.001$); R1 vs R3 – bias 0.09, LOA -6.4;6.6 ($r=0.94$, $p<0.001$); R2 vs R3 – bias -0.27, LOA -8.1;7.5 ($r=0.91$, $p<0.001$). Pearson correlation coefficients were excellent (>0.88) with significant p-values across all parameters ($p<0.001$). ICC were also excellent (>0.967).

Conclusion: 2DE and 3DE parameters of right ventricular (RV) systolic function are highly reproducible, independent of operator experience, in patients presenting with acute myocardial infarction.

Keywords: reproducibility, 3D echocardiography, 2D echocardiography, right ventricular systolic function, acute myocardial infarction.

What is new?

In acute myocardial infarction patients, parameters of right ventricular systolic function such as 2D TAPSE, S'T, FAC, as well as more the recently developed 3D right ventricular ejection fraction, have excellent reproducibility between operators with different levels of expertise.

INTRODUCTION

Echocardiographic assessment after acute myocardial infarction (AMI) focuses on left ventricular (LV) systolic function, given its prognostic significance and importance in guiding selection of appropriate therapies in these patients. [1] Right ventricular involvement is, however, frequently encountered in AMI patients. [2] Although frequently overlooked in this context, RV dysfunction has been shown to be a significant independent predictor of outcome, including arrythmias, in-hospital mortality, long-term mortality, and risk of developing heart failure. [3–11]

Routine evaluation of RV systolic function is done by measurement by 2D echocardiography (2DE) of tricuspid annular plane systolic excursion (TAPSE), right ventricular systolic wave velocity (S'_T), and fractional area change (FAC). [12,13] Recently, 3D echocardiographic (3DE) quantification of right ventricular ejection fraction (3D RVEF) has emerged as an alternative method for assessment of RV systolic function, although, it is not yet widely available and is considered to be dependent on the quality of image acquisition. Presence of RV dysfunction assessed by 3D RVEF has also been shown to be a predictor of mortality,

independent of left ventricular ejection fraction (LVEF). [14]

Although all of the aforementioned 2DE parameters have been shown to have prognostic significance in the context of AMI [3,6,15,16], recent data suggested that cut-off values for these parameters are only modestly associated with results obtained by 3D RVEF, resulting in significant misclassification of patients, depending on the parameter used and underlying pathology. [17] Furthermore, patients that had initially been found to have normal values of standard parameters but were subsequently reclassified as having RV dysfunction by 3D RVEF, had a 4-fold increase in mortality risk. [17]

Thus, our objective was to analyse reproducibility of assessment of RV systolic function by TAPSE, S'_T, FAC, and 3D RVEF, done by operators with different levels of experience, in a population of patients with AMI.

METHODS

Study Design and Patients. This was a single-center, prospective, observational study, that included patients hospitalized with AMI. All patients underwent coronary angiography and treatment, complying with the current European Society of Cardiology guidelines. [18,19] Local Ethics Committee approved the study protocol (Approval No. 14463/12.06.2018), while written informed consent for study participation was obtained before inclusion, during the first 24 hours of hospitalization.

The following inclusion criteria were used: (1) patients aged >18 years-old who signed an informed consent; (2) patients diagnosed with AMI according to the Fourth Universal Definition of Acute Myocardial Infarction; [20] (3) patients with sufficient image quality to perform 2DE and 3DE analysis (clear visualization of RV endocardium and tricuspid valve, lack of stitching artifacts). The exclusion criteria were: (1) patients with a history of heart failure (HF) or any documented LV (defined as LVEF<50%) or RV dysfunction (defined as TAPSE < 17mm, FAC < 35%, S'_T < 9.5 cm/s, 3D RVEF < 45%); (2) patients with a history of, or current atrial fibrillation; (3) patients with significant valvular disease; (4) patients with pulmonary hypertension.

Demographic and clinical data were retrieved from the clinical records obtained during hospitalization.

Two- and Three- Dimensional Echocardiography. Image acquisition was performed by the advanced echocardiographer with at least 5 years of training in 2DE and 3 years of training in 3DE. All examinations were performed within 48 hours of admission, using a state-of-the-art ultrasound system (Vivid E90 or Vivid E95 – GE Vingmed Ultrasound, Horten, Norway). Two-dimensional acquisitions were done using a M5 S probe, while a 4Vc-D probe was used for 3DE acquisition.

In accordance with current guidelines, image datasets were obtained using ECG-gated apical views optimised for the right ventricle. [12,13] Datasets of 2D images were digitally stored in raw-data format and analysed offline using commercially available dedicated software (EchoPAC version 203, GE Vingmed, Horten, Norway). Tricuspid annular plane systolic excursion (TAPSE) was obtained analysing M-mode acquisition with the cursor placed on the lateral tricuspid annulus in the A4C view optimised for the RV. Fractional area change (FAC) was calculated using ECG-gated end-diastolic and end-systolic area values obtained from A4C view optimised for the RV. Right ventricular systolic wave velocity (S'_T) was measured from tissue Doppler imaging (TDI) waveforms, obtained from placing the cursor at the lateral tricuspid annulus in A4C view optimised for the RV.

Three-dimensional datasets analysis was carried out offline, using semiautomated, commercially available software packages (4D Auto RV Quantification tool, EchoPAC version 203, GE Vingmed, Horten, Norway). Full volume 3D datasets were reconstructed using ECG gating from sequences of 6 cardiac cycles. Images were obtained using breath-hold techniques to avoid stiching artifacts. [13] The semi-automated tool used for 3D reconstruction required manual placement of a vertical axis through the center of the tricuspid valve and the RV apex, respectively. Points of interest were placed at the medial and lateral borders of the tricuspid annulus and at the RV apex. Subsequently, a multislice model showing endocardial border delineation at end-diastole and end-systole was displayed where manual corrections were performed to ensure accurate endocardial tracing. End-diastolic and end-systolic volumes were then automatically calculated by the software and provided together with a time-volume curve, 3D RVEF and other volumetric parameters values.

Measurements were done by three echocardiographers with different levels of expertise: advanced – labelled as Reader 1 (R1), with 5 years of experience in 2DE and 3 years of experience in 3DE, was also the one that carried out image

acquisition; intermediate – labelled as Reader 2 (R2), with 3 years of training in 2DE and 1 year of training in 3DE; beginner – labelled as Reader 3 (R3), with one year of training in 2DE and 3 months of training in 3DE. All measurements were independently performed in a blinded fashion on the same echocardiographic images. The sequence of reading was the following: Reader 1 conducted the initial assessment followed by Reader 2 and, finally, Reader 3.

Statistical analysis. Statistical analysis was performed using SPSS (ver. 26, IBM Corporation, Armonk, USA) and Microsoft Excel (ver. 2503, Microsoft Corporation, Redmond, USA). Continuous variables are expressed in mean ± SD, while categorical variables are presented as absolute numbers and percentages. Bland-Altman method was used to assess inter-observer variability and agreements by quantifying their mean difference (bias). Limits of agreement (LOA) were expressed as the mean difference ± 1.96*SD, thus defining the range within which 95% of individual differences are expected to lie. Agreements between measurements were assessed by Pearson's correlation coefficients with an R-value of > 0.80 considered a very good correlation, and p-value < 0.05 considered statistically significant. Intraclass correlation coefficients were quantified by the 2-way random effects with absolute agreement for multiple raters. ICC values were considered as follows: < 0.5 was considered poor, 0.5 ≤ ICC < 0.75 was considered moderate, 0.75 ≤ ICC < 0.90 was considered good and a value ≥ 0.90 was considered excellent.

RESULTS

Patients. Between December 2019 and June 2022, a total of 63 Caucasian patients were included. Study population consisted mainly of male patients (n = 52, 82.5%) with a mean age of 56.8 ± 10.3 years; Patient characteristics are presented in Table 1.

Table 1

Demographic and clinical characteristics

20	Total (n=63)
Demographic characteristics	
Age, years	56.86 ± 10.3
Male, n (%)	52 (82.5)
BMI, kg/m^2	28.57 ± 3.14
BSA, m^2	1.98 ± 0.21
AMI type and revascularization	
ST-segment elevation myocardial infarction, n (%)	43 (68.3)
Percutaneous coronary intervention, n (%)	54 (85.7)
Risk factors and medical history	
History of smoking, n (%)	38 (60.3)
Diabetes, n (%)	16 (25.4)
Hypertension, n (%)	44 (69.9)
Obesity, n (%)	21 (33.3)
Dyslipidaemia, n (%)	61 (96.8)
Peripheral artery disease, n (%)	1 (1.6)
Chronic kidney disease, n (%)	17 (27.0)

Abbreviations: AMI – acute myocardial infarction, BMI – body mass index, BSA – body surface area

Comparison of TAPSE measurements provided by the three operators with different levels of experience. Bland-Altman plots showed a bias of 0.24 (95% CI: -0.08;0.55) between the advanced and intermediate readers, with LOA of -2.27 (95% CI -2.82;-2.27) to 2.75 (95% CI 2.2;3.29); 0.38 (95% CI: 0.09;0.76) between the advanced and beginner readers, with LOA of -1.9 (95% CI -2.45;-1.94) to 2.7 (95% CI 2.19;3.21); and 0.14 (95% CI -0.17;0.46) between the intermediate and beginner readers, with LOA of -2.37 (95% CI -2.92;-2.37) to 2.65 (95% CI 2.11-3.2) (Figure 1.A). All Pearson correlations were good (R1 vs R2: r=0.93, p<0.001; R1 vs R3: r=0.94, p<0.001; R2 vs R3: r=0.93, p<0.001) (Figure 1.B). ICC was excellent with a value of 0.977 (95% CI: 0.965–0.985).

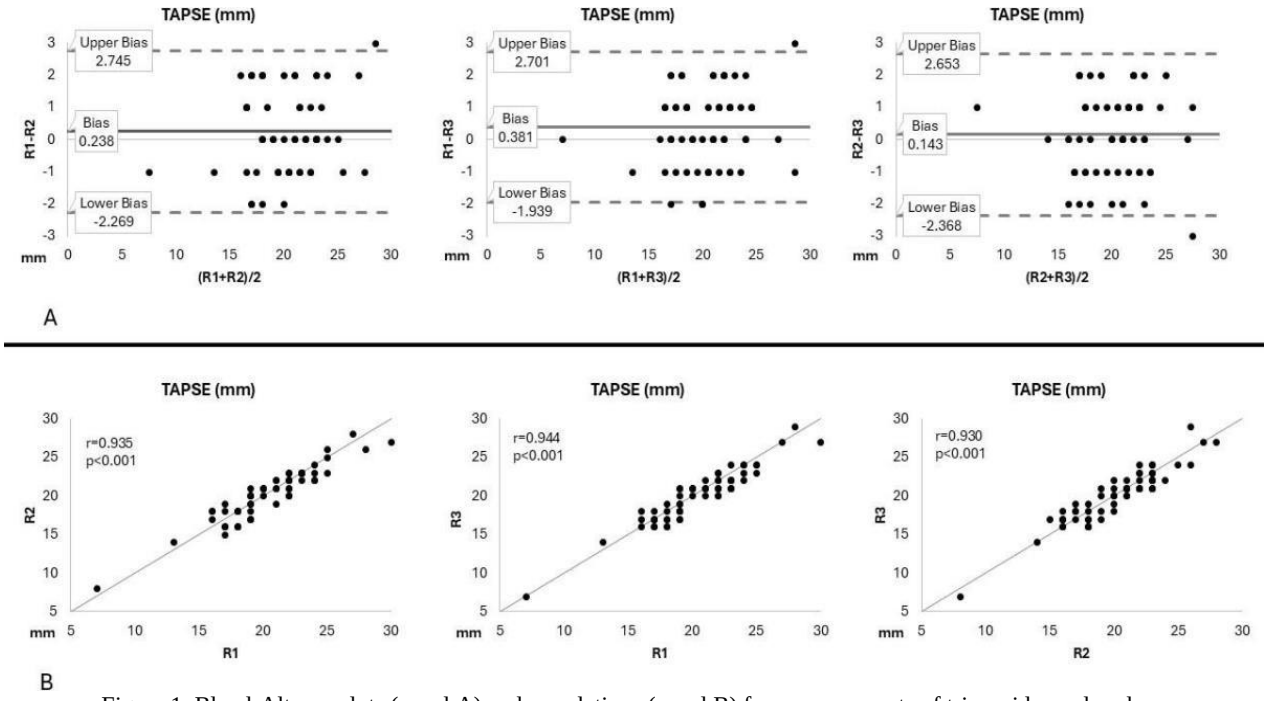


Figure 1. Bland-Altman plots (panel A) and correlations (panel B) for measurements of tricuspid annular plane systolic excursion (TAPSE) by advanced (R1), intermediate (R2), and beginner (R3) readers.

Comparison of S'T measurements provided by the three operators with different levels of experience. Bland-Altman plots showed a bias of 0.19 (95% CI 0;0.38) between the advanced and intermediate readers, with LOA of -1.3 (95% CI -1.62;-1.3) to 1.7 (95% CI 1.35;2); 0.37 (95% CI 0.11;0.62) between the advanced and beginner readers, with LOA of -1.64 (95% CI -2.07;-1.64) to 2.37 (95% CI 1.93;2.8); and 0.17 (95% CI -0.13;0.48) between the intermediate and beginner readers, with LOA of -2.25 (95% CI -2.78;-2.25) to 2.6 (95% CI 2.07;3.13) (Figure 2.A). All Pearson correlations were good (R1 vs R2: r=0.96, p<0.001; R1 vs R3: r=0.90, p<0.001; R2 vs R3: r=0.88, p<0.001) (Figure 2.B). ICC 0.967 (95% CI: 0.95–0.98) also showed excellent reproducibility.

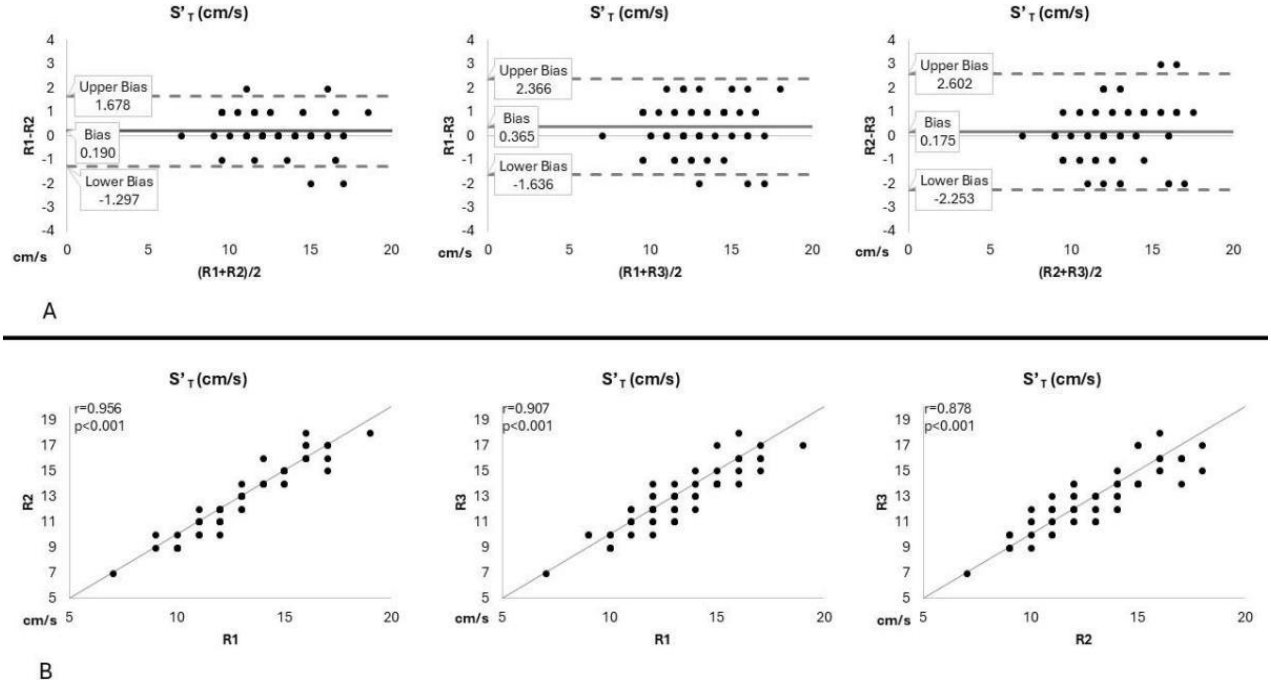


Figure 2. Bland-Altman plots (panel A) and correlations (panel B) for measurements of right ventricular systolic wave velocity (S'_T) by advanced (R1), intermediate (R2), and beginner (R3) readers.

Comparison of FAC measurements provided by the three operators with different levels of experience. Bland-Altman plots showed a bias of 0.36 (95% CI -0.3;1.02) between the advanced and intermediate readers, with LOA of -4.9 (95% CI -6.05;-4.9) to 5.62 (95% CI 4.47;6.77); 0.09 (95% CI -0.73;0.91) between the advanced and beginner readers, with LOA of -6.44 (95% CI -7.86;-6.44) to 6.6 (95% CI 5.19;8.04); and -0.27 (95% CI -1.25;0.71) between the intermediate and beginner readers, with LOA of -8.07 (95% CI -9.77;-8.07) to 7.53 (95% CI 5.83;9.23) (Figure 3.A). All Pearson correlations were good (R1 vs R2: r=0.96, p<0.001; R1 vs R3: r=0.94, p<0.001; R2 vs R3 r=0.91, p<0.001) (Figure 3.B). ICC value was 0.98 (95% CI: 0.97–0.99) showing excellent correlation.

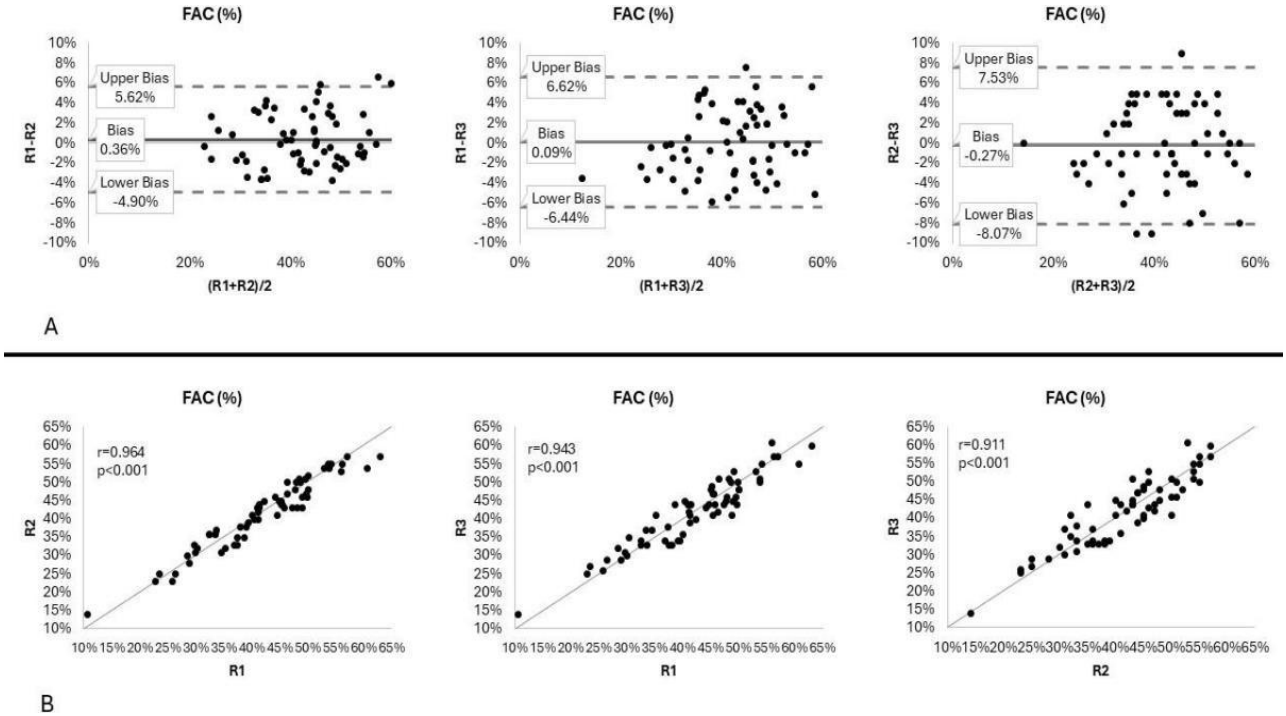


Figure 3. Bland-Altman plots (panel A) and correlations (panel B) for measurements of fractional area change (FAC) by advanced (R1), intermediate (R2), and beginner (R3) readers.

Comparison of 3D RVEF measurements provided by the three operators with different levels of experience. Bland-Altman plots showed a bias of -0.02 (95% CI -0.64;0.60) between the advanced and intermediate readers, with LOA of -4.96 (95% CI -6.03;-4.96) to 4.91 (95% CI 3.84;5.99); -0.38 (95%CI -1.15;0.39) between the advanced and beginner readers, with LOA of -6.48 (95% CI -7.81;-6.48) to 5.72 (95% CI 4.39;7.05) ; and -0.36 (95% CI -1.01;0.3) between the intermediate and beginner readers, with LOA of -5.57 (95% CI - 6.70;-5.57) to 4.85 (95% CI 3.72;5.99) (Figure 4.A). All Pearson correlations were good (R1 vs R2: r=0.96, p<0.001; R1 vs R3: r=0.93, p<0.001; R2 vs R3 r=0.94, p<0.001) (Figure 4.B). ICC value was 0.98 (95% CI: 0.97–0.99).

Comparative values of interobserver variability and agreement are provided in Table 2.

DISCUSSIONS

Currently, 2DE is the most widely used method to assess RV systolic function in clinical practice. All three parameters used in this study have previously been shown to have good correlations with other imaging methods. TAPSE has been shown to have a strong correlation with RVEF obtained by CMR [21] and radionuclide angiography [22], FAC displayed strong correlation with RVEF values obtained by CMR [23], while S'_T has been previously validated by both methods. [24,25] Previous studies have also shown that both TAPSE [26–29] and S'_T [26] are highly reproducible parameters, while FAC values had low concordance for both intra- and inter-observer variability, probably because of dependance on the quality of endocardial border delineation. [26] However, we have not found any studies assessing inter-observer variability between operators with

different level of expertise. The low bias values and narrow LOA intervals obtained in our study showed that, in a population of patients with AMI, inter-observer reproducibility of TAPSE, S'_T, and FAC is excellent, and independent of operator experience. The differences regarding FAC reproducibility values in our study and previously reported data may arise from the fact that included patients had sufficient image quality for 3DE analysis and acquisition was done using the A4C view optimised for the right ventricle. It is noticeable that, except for FAC, bias values were lower between the advanced and intermediate operators, suggesting the existence of a learning curve for these parameters. This is an important message for everyday clinical practice, suggesting that 2DE evaluation of RV can be carried out with consistent results, even by less-experienced operators, without the risk of misdiagnosis when image acquisition is carried out by an experienced echocardiographer in in apical 4-chamber view optimised for the right ventricle.

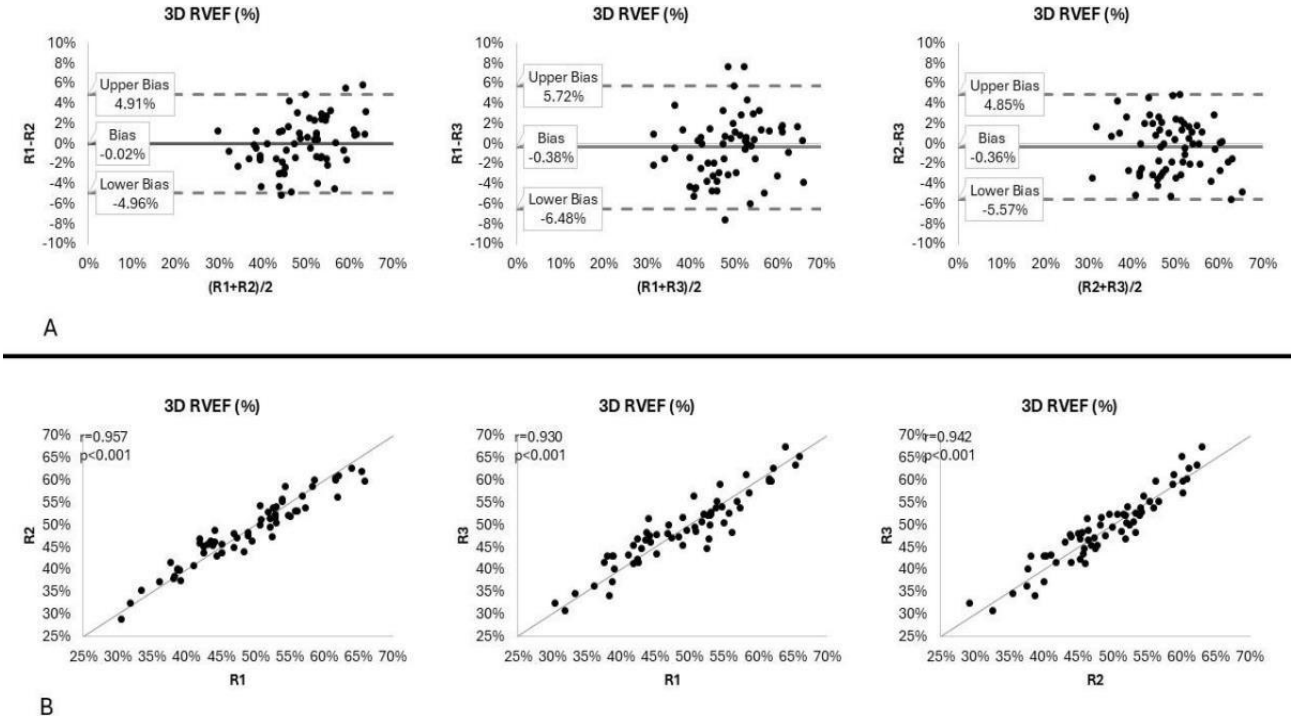


Figure 4. Bland-Altman plots (panel A) and correlations (panel B) for measurements of 3D Right ventricular ejection fraction (3D RVEF) by advanced (R1), intermediate (R2), and beginner (R3) readers.

Table 2

Interobserver variability and agreement between echocardiographers with different levels of experience for TAPSE, S'_T, FAC, and 3D RVEF

R1 vs R2	**TAPSE**	**S'T**	**FAC**	**3D RVEF**
Bias	0.24	0.19	0.36	-0.02
(95% CI)	(-0.08;0.55)	(0.0;0.38)	(-0.3;1.02)	(-0.64;0.6)
Lower LOA	-2.27	-1.3	-4.9	-4.96
(95% CI)	(-2.82; -2.27)	(-1.62;-1.3)	(-6.05;-4.9)	(-6.03;-4.96)
Upper LOA	2.75	1.68	5.62	4.91
(95% CI)	(2.20;3.29)	(1.35;2.0)	(4.47;6.77)	(3.84;5.99)
R1 vs R3	**TAPSE**	**S'T**	**FAC**	**3D RVEF**
Bias	0.38	0.36	0.09	-0.38
(95% CI)	(0.09;0.67)	(0.11;0.62)	(-0.73;0.91)	(-1.15;0.39)

Lower LOA (95% CI)	-1.94 (-2.45;-1.94)	-1.64 (-2.07;-1.64)	-6.44 (-7.86;-6.44)	-6.48 (-7.81;6.48)
Upper LOA (95% CI)	2.7 (2.19;3.21)	2.37 (1.93;2.80)	6.62 (5.19;8.04)	5.72 (4.39;7.05)
R2 vs R3	**TAPSE**	**S'T**	**FAC**	**3D RVEF**
Bias	0.14 (-0.17;0.46)	0.17 (-0.13;0.48)	-0.27 (-1.25;0.71)	0.36 (-1.01;0.3)
Lower LOA (95% CI)	-2.37 (-2.92;-2.37)	-2.25 (-2.78;-2.25)	-8.07 (-9.77;-8.07)	-5.57 (-6.7;-5.57)
Upper LOA (95% CI)	2.65 (2.11;3.2)	2.60 (2.07;3.13)	7.53 (5.83;9.23)	4.85 (3.72;5.99)
ICC (95% CI)	0.977 (0.965–0.985)	0.967 (0.95–0.98)	0.98 (0.97–0.99)	0.98 (0.97–0.99)

Abbreviations: 3D RVEF – three-dimensional right ventricular ejection fraction, FAC – fractional area change, ICC – intraclass correlation coefficient, LOA – limits of agreement, TAPSE – tricuspid annular plane systolic excursion, S'T – right ventricular systolic wave velocity.

3DE assessment of right ventricular function by 3D RVEF has recently emerged as an alternative to 2DE methods, being extensively validated with CMR measurements, with correlation coefficients R>0.75 in most studies. [30] 3D RVEF measurements are highly reproducible, with low intra- and inter- observer variability varying from 0 to 0.9% in most studies. [30–35] A frequently cited limitation is operator experience, but recent studies have addressed this issue, showing that 3DE quantification provides good reproducibility even in novice operators. [35–37] Our study also demonstrated very good values of reproducibility that are similar to those found for 2DE parameters. Moreover, bias between the advanced and intermediate user was the lowest in the entire study, while bias when comparing with the beginner operators were similar to the 2DE parameters. Thus, although 3D RVEF assessment exhibits a learning curve, our study suggests that it is highly reproducible among operators with different levels of experience when image acquisition is carried out by an advanced operator.

Limitations. The current study has a series of limitations that must be acknowledged. These are related mostly to the inherent limitations of 3D echocardiography. Image quality is essential for 3D RVEF assessment, but also FAC. Image acquisition was carried out only by the advanced echocardiographer, and caution should be taken in considering that these results can be extended to a scenario in which acquisition is made by multiple operators with different levels of expertise. However, it is a common scenario in institutions that image acquisition is carried out by an experienced practicioner, followed by offline analysis by operators with different levels of expertise. Further analysis in this direction is warranted to clarify our better understanding of feasibility and reproducibility of 3DE RVEF assessment when image acquisition is carried out by less experienced operators. Patients with history of heart failure, documented LV or RV dysfunction, atrial fibrillation, significant valvular disease and pulmonary hypertension were excluded from our study. Multi-beat full-volume acquisition remains the recommended method for obtaining adequate temporal resolution, and highly irregular rhythms such as atrial fibrillation can generate significant artifacts. [13,38] Pre-existing ventricular dysfunction, valvular disease and pulmonary hypertension can result in significantly enlarged and deformed RVs that can also lead to poor image quality. [38] As such, our findings cannot be extended to these categories of patients. Finally, our study did not include patients evaluated by CMR, which remains the gold standard of RV quantification. However, CMR is currently not widely available for all

patients in everyday clinical use due to its costs, non-portable nature and significant patient-related contraindications. Moreover, our study was focused on reproducibility of echocardiographic parameters of RV systolic function that have all been previously validated by CMR.

Conclusions. Our study demonstrates that both 2DE, as well as more advanced 3DE parameters of right ventricular systolic function, are highly reproducible, and independent of operator experience when image acquisition is carried out by an advanced echocardiographer. Our findings support the use of these methods in current clinical practice in patients with AMI, in cases when CMR is not available, given that RV function assessment has been shown to provide supplemental prognostic value in addition to standard evaluation of left ventricular function.

Scop: *Evaluarea reproductibilității parametrilor ecocardiografici bidimensionali (2DE) ai funcției sistolice ventriculare drepte – excursia sistolică a planului inelului tricuspidian (TAPSE), viteza sistolică a undei ventriculului drept (S'T), fracția de schimbare a ariei (FAC) – și a fracției de ejecție ventriculare drepte măsurată prin ecocardiografie tridimensională (3DE), prin determinări efectuate de operatori cu niveluri diferite de experiență, la pacienți cu infarct miocardic acut.*

Metode: *Măsurătorile au fost realizate offline, independent, de trei ecocardiografiști cu niveluri diferite de experiență: Cititor 1 – avansat (5 ani de pregătire în 2DE, 3 ani în 3DE); Cititor 2 – intermediar (3 ani de pregătire în 2DE, 1 an în 3DE); Cititor 3 – începător (1 an de pregătire în 2DE, 3 luni în 3DE).*

Variabilitatea interobservator și concordanța între cititori au fost comparate utilizând grafice Bland-Altman (ca bias și limite de concordanță – LOA), corelații Pearson și coeficienți de corelație intraclasați (ICC).

Rezultate: *Au fost analizați 63 de pacienți (52 bărbați, vârsta medie 56,8±10,3 ani). Toate măsurătorile au demonstrat o variabilitate interobservator și o concordanță excelente. Valorile bias-ului au fost reduse, iar intervalele LOA înguste pentru toți parametrii analizați. În general, bias-ul a fost mai scăzut între cititorul avansat și cel intermediar, cu excepția FAC: R1 vs R2 – bias 0,36, LOA -4,9;5,62 (r=0,96, p<0,001); R1 vs R3 – bias 0,09, LOA -6,4;6,6 (r=0,94, p<0,001); R2 vs R3 – bias -0,27, LOA -8,1;7,5 (r=0,91, p<0,001).*

Coeficienții de corelație Pearson au fost excelenți (>0,88) cu valori p semnificative pentru toți parametrii (p<0,001). ICC au fost, de asemenea, excelente (>0,967).

Concluzii: *Parametrii 2DE și 3DE ai funcției sistolice ventriculare drepte sunt extrem de reproductibili, independent de experiența operatorului, la pacienții cu infarct miocardic acut.*

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Funding: Public grant(s) – EU funding – UEFISCDI. Project number grant 5/2018; INNATE- IM: Targeting innate immune system mechanisms for a better risk stratification and identification of new therapeutic options in acute myocardial infarction.

Acknowledgment: The study authors have no further acknowledgments to make.

Conflicts of Interest: The authors declare no conflict of interest.

REFERENCES

1. TIMMIS A., ABOYANS V., VARDAS P., TOWNSEND N., TORBICA A., KAVOUSI M., *et al. European Society of Cardiology: the 2023 Atlas of Cardiovascular Disease Statistics*. Eur Heart J. 2024;45(38):4019–4062.
2. STIERMAIER T., BACKHAUS S.J., MATZ J., KOSCHALKA A., KOWALLICK J., DE WAHA-THIELE S., *et al. Frequency and prognostic impact of right ventricular involvement in acute myocardial infarction*. Heart. 2021;107(3):209–215.
3. ZORNOFF L.A.M., SKALI H., PFEFFER M.A., *et al. Right ventricular dysfunction and risk of heart failure and mortality after myocardial infarction*. J Am Coll Cardiol. 2002;39(9):1450–1455.

4. BUENO H., LÓPEZ-PALOP R., BERMEJO J., LÓPEZ-SENDON J.L., DELCAN J.L. *In-hospital outcome of elderly patients with acute inferior myocardial infarction and right ventricular involvement*. Circulation. 1997;96(2):436–441.
5. SHAHAR K., DARAWSHA W., YALONETSKY S., *et al. Time dependence of the effect of right ventricular dysfunction on clinical outcomes after myocardial infarction: role of pulmonary hypertension*. J Am Heart Assoc. 2016;5(7).
6. ANAVEKAR N.S., SKALI H., BOURGOUN M., *et al. Usefulness of right ventricular fractional area change to predict death, heart failure, and stroke following myocardial infarction (from the VALIANT ECHO Study).* Am J Cardiol. 2008;101(5):607–612.
7. LAROSE E., GANZ P, REYNOLDS H.G., *et al. Right ventricular dysfunction assessed by cardiovascular magnetic resonance imaging predicts poor prognosis late after myocardial infarction*. Am J Cardiol. 2007;99(8):855–862.
8. MASCI P.G., FRANCONE M., DESMET W., *et al. Right ventricular ischemic injury in patients with acute ST-segment elevation myocardial infarction: characterization with cardiovascular magnetic resonance*. Circulation. 2010;122(14):1405–1412.
9. JENSEN C.J., JOCHIMS M., HUNOLD P., SABIN G., SCHLOSSER T., BRUDER O. *Right ventricular involvement in acute left ventricular myocardial infarction: prognostic implications of MRI findings*. Am J Roentgenol. 2010;194(3):592–598.
10. MEHTA S.R., EIKELBOOM J.W., NATARAJAN M.K., DIAZ R., YI C., GIBBONS R.J., YUSUF S. *Impact of right ventricular involvement on mortality and morbidity in patients with inferior myocardial infarction*. J Am Coll Cardiol. 2001;37(1):37–43.
11. MUTLAK D., LESSICK J., SHEMY CARASSO S., *et al. Utility of pulmonary hypertension for the prediction of heart failure following acute myocardial infarction*. Am J Cardiol. 2012;109(9):1254–1259.
12. LANG R.M., BADANO L.P., MOR-AVI V., *et al. Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging*. J Am Soc Echocardiogr. 2015;28(1):1-39.e14.
13. MUKHERJEE M., RUDSKI L.G., ADDETIA K., *et al. Guidelines for the Echocardiographic Assessment of the Right Heart in Adults and Special Considerations in Pulmonary Hypertension: Recommendations from the American Society of Echocardiography*. J Am Soc Echocardiogr. 2025;38(3):141–186.
14. SURKOVA E., MURARU D., GENOVESE D., ARUTA P., PALERMO C., BADANO L. *Relative prognostic importance of left and right ventricular ejection fraction in patients with cardiac diseases*. J Am Soc Echocardiogr. 2019;32(11):1407–1415.e3.
15. POLEDNICZEK M., KAMMERLANDER A., JANSEN C., *et al. Right ventricular strain and tricuspid annular plane systolic excursion are associated with mortality in inferior ST-elevation myocardial infarction*. Eur J Clin Invest. 2025; 55:e70014.
16. AWAD E.M.L., MAHMOUD A.H., MAGHRBY K.S., TAHA N.M., IBRAHIM A.M. *Short-term prognostic value of TAPSE, RVFAC, and tricuspid S' wave peak systolic velocity after first acute myocardial infarction*. BMC Res Notes. 2020;13(1).
17. TOLVAJ M., JANSEN C., *et al. Significant disagreement between conventional parameters and 3D echocardiography-derived ejection fraction in the detection of right ventricular systolic dysfunction and its association with outcomes*. J Am Soc Echocardiogr. 2021;37(7):677–686.
18. COLLET J.-P., THIELE H., BARBATO E., *et al. 2020 ESC guidelines for the management of acute coronary syndromes in patients presenting without persistent ST-segment elevation: the Task Force for the Management of Acute Coronary Syndromes of the European Society of Cardiology (ESC).* Eur Heart J. 2021;42:1289–1367.
19. IBANEZ B., JAMES S., AGEWALL S., *et al. 2017 ESC guidelines for the management of acute myocardial infarction in patients presenting with ST-segment elevation: the Task Force for the Management of Acute Myocardial Infarction of the European Society of Cardiology (ESC).* Eur Heart J. 2018;39:119–177.
20. THYGESEN K., ALPERT J.S., JAFFE A.S., *et al. Fourth Universal Definition of Myocardial Infarction*. Circulation. 2018;138(20):e618–e651.
21. PAVLICEK M., WAHL A., RUTZ T., *et al. Right ventricular systolic function assessment: Rank of echocardiographic methods vs cardiac magnetic resonance imaging*. Eur J Echocardiogr. 2011;12(11):871–80.
22. KAUL S., TEI C., HOPKINS J.R., SHAH P.M. *Assessment of right ventricular function using two-dimensional echocardiography.* Am Heart J. 1984;107(3):526–531.
23. ANAVEKAR N.S., GERSON D., SKALI H., KWONG R.Y., YUCEL E., SOLOMON S.D. *Two-dimensional assessment of right ventricular function: an echocardiographic–MRI correlative study*. Echocardiography. 2007;24(5):452–456.
24. SCHWERZMANN M., SAMMAN A.M., SALEHIAN O., *et al. Comparison of echocardiographic and cardiac magnetic resonance imaging for assessing right ventricular function in adults with repaired tetralogy of Fallot*. Am J Cardiol. 2007;99(11):1593–1597.
25. UETI O.M. *Assessment of right ventricular function with Doppler echocardiographic indices derived from tricuspid annular motion: comparison with radionuclide angiography*. Heart. 2002;88(3):244–248.
26. PINEDO M., VILLACORTA E., TAPIA C., *et al. Inter- and intra-observer variability in the echocardiographic evaluation of right ventricular function*. Rev Esp Cardiol. 2010;63(7):802–809.
27. PREVITERO M., SIMETI G., LORENZONI G., *et al. Feasibility and reproducibility of right ventricle stress echocardiography and its capability to assess the right ventricle contractile reserve of patient with at least trivial tricuspid regurgitation*. Eur Heart J Cardiovasc Imaging. 2021;22(Suppl 1):jeaa356.194.
28. OLMOS-TEMOIS S.G., SANTOS-MARTÍNEZ L.E., ÁLVAREZ-ÁLVAREZ R., *et al. Interobserver agreement on the echocardiographic parameters that estimate right ventricular systolic function in the early postoperative period of cardiac surgery*. Medicina Intensiva (English Edition). 2016;40(8):491–498.
29. FORFIA P.R., FISHER M.R., MATHAI S.C., *et al. Tricuspid annular displacement predicts survival in pulmonary hypertension*. Am J Respir Crit Care Med. 2006;174(9):1034–1041.
30. AHMAD A., LI H., ZHANG Y., *et al. Three-dimensional echocardiography assessment of right ventricular volumes and function: Technological perspective and clinical application*. Diagnostics. 2022;12:806.
31. LASER K.T., HORST J.P., BARTH P., *et al. Knowledge-based reconstruction of right ventricular volumes using real-time three-dimensional echocardiographic as well as cardiac magnetic resonance images: Comparison with a cardiac magnetic resonance standard*. J Am Soc Echocardiogr. 2014;27(10):1087–1097.

32. OTANI K., NABESHIMA Y., KITANO T., *et al. Accuracy of fully automated right ventricular quantification software with 3D echocardiography: Direct comparison with cardiac magnetic resonance and semi-automated quantification software*. Eur Heart J Cardiovasc Imaging. 2019;21(7):787–795.
33. KNIGHT D.S., GRASSO A.E., QUAIL M.A., *et al. Accuracy and reproducibility of right ventricular quantification in patients with pressure and volume overload using single- beat three-dimensional echocardiography*. J Am Soc Echocardiogr. 2015;28(3):363–374.
34. AHMAD A., LI H., WAN X., *et al. Feasibility and accuracy of a fully automated right ventricular quantification software with three-dimensional echocardiography: Comparison with cardiac magnetic resonance*. Front Cardiovasc Med. 2021;8:732893.
35. DE POTTER T., WEYTJENS C., MOTOC A., *et al. Feasibility, reproducibility and validation of right ventricular volume and function assessment using three-dimensional echocardiography*. Diagnogstics. 2021;11(4):699.
36. BALDEA S.M., VELCEA A.E., RIMBAS R.C., *et al. 3-D echocardiography is feasible and more reproducible than 2-D echocardiography for in-training echocardiographers in follow-up of patients with heart failure with reduced ejection fraction*. Ultrasound Med Biol. 2021;47(3):499–510.
37. MEMIS H., BALDEA S.M., MIHALCEA D., *et al. Short period of training in 3D echocardiography provides good feasibility and reproducibility of right ventricular assessment in heart failure*. Eur Heart J Cardiovasc Imaging. 2023;24(Suppl 1).
38. ADDETIA K., MURARU D., BADANO L.P., LANG R.M. *New Directions in Right Ventricular Assessment Using 3-Dimensional Echocardiography*. JAMA Cardiology. 2019;4(9):936.

Received: 18th July 2025