Assessment of LV Function by Three-Dimensional and Three-Dimensional Speckle Tracking Echocardiography after Percutaneous Coronary Intervention for Chronic Total Occlusion Coronary Artery Disease

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ABSTRACT
Background: Cardiovascular disease is the most leading cause of morbidity and mortality throughout the world today. Chronic total occlusions are defined as 100% occlusions with TIMI flow 0 with at least 3-month duration. New echocardiographic techniques is an important noninvasive method for assessing cardiovascular function and mechanics.
Objective: Determination of the impact of revascularization for chronic total occlusion coronary artery disease on left ventricular function using three-dimensional and three- dimensional speckle tracking echocardiography.
Patients and methods: The present study included (60) patients presenting with chronic total occlusion coronary artery disease at Al-Azhar University Hospitals, in the period between December 2015 and April 2018. The study compared the differences in echocardiographic parameters before the procedure (pre-procedure) and one month after successful PCI to CTO (post- procedure). Two-dimensional (2D) and three- dimensional (3D) transthoracic echocardiography (baseline and follow up study), 2D Global longitudinal strain (GLS) and 3D longitudinal strain (LS) speckle tracking echocardiography (base line and follow up study) were done.
Results: Mean left ventricular ejection fraction significantly increased, while the left ventricular end-diastolic and end-systolic volumes significantly decreased. The left ventricular end-systolic and end-diastolic volumes and diameters were significantly decreased. The global longitudinal strain (2DSTE and 3DSTE) showed significant improvement after successful revascularization. Both patients with LVEF ≥ 50% and LVEF < 50% displayed significant improvement in the 2D GLS and 3D LS, also diabetic and non-diabetic patients displayed significant improvement in the 2D GLS and 3D LS. Improvement in the 2D GLS % was correlated with an improvement in the 3D LS %.
Conclusion: Restoring the coronary blood flow in chronic total occlusion patients reduces the left ventricular volumes, dimensions and improves the left ventricular ejection fraction and global longitudinal strain of hibernating myocardium.
Keyword: Chronic Total Occlusions, Left Ventricular Function, New echocardiographic technique, Percutaneous Coronary Intervention.

INTRODUCTION

Cardiovascular disease is the leading cause of morbidity and mortality throughout most of the world today, representing 31% of all deaths [1]. Coronary artery disease is the most common cardiovascular disease and its incidence increases in the elderly [2]. Population aging and the increase of risk factors such as arterial hypertension and diabetes associated with obesity have greatly contributed to increased hospitalizations of patients with acute coronary syndrome (ACS) [3]. Coronary chronic total occlusions (CTOs) are defined as 100% occlusions with TIMI (Thrombolysis in Myocardial Infarction) 0 flow with at least a 3-month duration [4]. Echocardiography is an important noninvasive method for assessing cardiovascular function and mechanics [5]. Recently, the use of two-dimensional speckle-tracking echocardiography (2D-STE) for measurement of myocardial strain has gained importance for its applicability in the clinical practice. Its high sensitivity to measure systolic function and identify left ventricular subclinical

dysfunction, as compared with left ventricular ejection fraction, extends its applicability and makes it a test of additional value in many areas of cardiology [6]. Despite promising data, 2D-STE has not been sufficiently standardized as a routine method for the diagnosis of myocardial ischemia. Characteristics inherent to the technique affect its applicability in both acute and chronic phase of the ischemic event, as previous ventricular deformities may affect the interpretation of results [7]. The study by **dos Santos et al.** [8] provides us with a pioneer study on the real applicability of left ventricular longitudinal strain in UA. The authors described the frequency at which 2D-STE is indicated in cardiac emergencies and evaluated the values of the test in patients with severe coronary artery lesions. Two dimensional speckle tracking echocardiography is based on tracking the characteristic speckle patterns created by interference of ultrasound beams in the myocardium and its accuracy has been confirmed using son micrometry and magnetic resonance imaging as reference methods [9]. Measurements of S and SRs are more sensitive than standard

echocardiographic parameters for assessing left ventricular (LV) function of many clinical conditions, including cardiomyopathy and CAD [10]. Standard echocardiography has several targets in the cardiac population, as the assessment of myocardial performance, valvular and/or congenital heart disease, and hemodynamics. Three-dimensional echocardiography gained attention recently as a viable clinical tool in assessing left ventricular (LV) and right ventricular (RV) function, volume, and shape [11]. The improved capability of real-time 3DE includes visualization of heart structures with depth, assessment of cardiac lesions from any perspective, and quantification of volumes without geometric assumption. The technology enables accurate, precise, detailed understanding of the pathophysiologic nature of diseases. 3DE data acquisition includes simultaneous multi plane mode, real-time 3D mode narrow sector, focused wide sector-zoom mode, full volume-gated acquisition, and full volume with color flow Doppler [12]. In 3DE, the LV end-diastolic volume (EDV) and end-systolic volume (ESV) are measured by semi-automatic border delineation in 3D space with manual adjustment when required. In cases where border delineation is still difficult owing to trabeculae or poorly defined with 3DE imaging, contrast agents maybe infused to enhance LV opacification. The 3DE eliminates geometric assumption or circumvents foreshortened views that are the common source of errors in 2DE. In addition, several studies have shown that LV mass determined by 3DE also correlated better with CMR compared to 2DE with CMR [13]. Three-dimensional speckle tracking echocardiography (3DSTE) has recently been regarded as a more promising technique to accurately and reproducibly evaluate the segmental and global LV function [14].

PATIENTS AND METHODS

The present study was a prospective study included (60) patients presenting with chronic total coronary artery occlusion at Al-Azhar University Hospitals, in the period between December 2015 and April 2018. The study compared the difference in echocardiographic parameters between the pre procedure value and first month after successful PCI to CTO (post procedure). **The study was approved by the Ethics Board of Al-Azhar University and an informed written consent was taken from each participant in the study.**
Inclusion criteria: Patients with chronic total coronary artery occlusion which was defined as lumen compromise resulting in either TIMI flow grade 0 or 1, with a likely duration of more than 3 months documented by history, clinical examination, resting electrocardiography, transthoracic echocardiography and coronary angiography. Patients who had successful percutaneous coronary intervention to chronic total occlusion.
Exclusion criteria: Patients who had failed percutaneous coronary intervention to chronic total occlusion. Any coronary lesions which not considered chronic total occlusion.
Methods: Informed consent was taken. Full history taking and examination to assess: Cardiovascular risk factors e.g. smoking , obesity, diabetes mellitus and hypertension that is defined as BP values ≥ 140 mmHg SBP and/or ≥ 90 mmHg DBP on 2 separate occasions and or on antihypertensive treatment regularly[15].
Laboratory investigations: including complete blood picture, fasting blood glucose, HbA1c, serum lipogram, serum creatinine, liver function tests, and serology for hepatitis B and C.
Clinical Examination: Full clinical examination were carried out, chest and heart examination for heart sounds, additional heart sounds, murmurs and the back for lung congestion. Electrocardiography (ECG) were done by an investigator to diagnose chronic ischemic heart disease, using resting 12-leads ECG.
Two-dimensional transthoracic echocardiography (baseline study): Vivid E95 phased array system equipped with TDI, speckle tracking and three-dimensional technologies was used. Two dimensional transthoracic echocardiography was done before and one month after successful percutaneous coronary intervention. All the patients were examined in the left lateral decubitus position. Echocardiographic images were acquired from the standard views (parasternal long-axis, parasternal short axis, apical four-chamber, apical five-chamber and apical two-chamber views) [16]. Left ventricular systolic function was assessed. Measurement of LV Ejection fraction (EF%) and fractional shortening (FS%) were done. Assessment of left ventricular systolic function two-dimensional echocardiography using the Simpson's method. In this method the left ventricle is divided into 20 sections of known thickness. The computer takes multiple short-axis slices at different levels. The volume of each slice is area multiplied by its thickness. LVEF % was calculated as percentage change of LV chamber volumes between diastole and systole. The LV ejection fraction (EF %) was automatically calculated as follows: EF% = (EDV – ESV) / EDV × 100 [17].
Two-dimensional speckle tracking (Global longitudinal strain): Generally two-dimensional ultrasonic detectors were used to collect images of

the apical two-chamber, apical four-chamber and apical three-chamber views. During the inspection, all patients were connected to timing electrocardiography and maintained in the left lateral decubitus position. This involved entering two-dimensional speckle tracking mode, adjusting the baseline and angle, clearly displaying the image of the endocardium, mitral annulus and apex, and speckle assignment separately. The curve of the endocardium was drawn and the software analyzed the data and calculated the peak value longitudinal strain of 17 sections of the left ventricle and the time to peak value of the strain [18].

Three-dimensional transthoracic and 3D speckle tracking echocardiography (baseline study): Three-dimensional transthoracic echocardiography was done before successful percutaneous coronary intervention. Real-time three-dimensional echocardiography images were obtained from an apical window with the patient in the same position as for two-dimensional speckle tracking echocardiography. Full-volume images were gathered over four cardiac cycles using a matrix array transducer. Measurements of the three dimensional-left ventricular volumes, the three dimensional ejection fraction and three dimensional speckle tracking were performed off-line. Recently, published EAE/ASE guidelines recommend the use of 3D echocardiography in assessing LV volumes and ejection fraction as a more accurate and reliable modality. Latest advances in speckle tracking echocardiography (STE) also allow us to track speckles in all three dimensions simultaneously in a full-volume data set [19].

Coronary angiography: Transfemoral standard technique is used in all patients using 6 Fr sheath. All procedures were performed using Siemens Axiom Arts and Philips Allura Xper FD 10/10. The procedures and lesions identifications were performed by expert interventional cardiologists.

1. Pre-procedural preparation: a) Informed consent: A detailed discussion with the patient and family for indications, benefits, potential complications, possibility to need emergency CABG as well as alternative options then an informed consent was taken. b) Patient should be fasting several hours before procedure. c) Medications: All medications are continued till morning of the procedure. Aspirin 325mg orally is given before the procedure. If the patient is not on Clopidogril 75 mg, a loading dose of 600 mg PO is given prior to the procedure. d) Education: Patients were warned that they may feel nauseated or may experience a hot sensation lasting for about 30 seconds due to the injections of non-ionic contrast dye (Optiray. USA). Also, they are instructed to cough once they hear anyone in the room say "cough" which is a maneuver to accelerate resolution of dye-induced bradycardia. e) Equipment: i. Continuous blood pressure & ECG monitoring of heart rate, rhythm & ST segments during the whole procedure is essential. ii. Resuscitation equipment, in particular defibrillators & intubation trays, are always tested & ready. 2. PCI procedure: (a) Access site: Trans femoral standard technique is used in all patients using 6 Fr sheath. (b) Intraprocedural medications: As soon as the arterial sheath is in place, a dose of 10.000 units of heparin is injected intravenously. If the procedure continues for more than 1 hour, another 5000 units of heparin is given. (c) Coronary angiography was performed assessing: CTO lesion as regards: 1. Site of the occlusion. 2. Length of the occlusion. 3. TIMI flow grade. 4. If calcified, degree of calcification. 5. Collaterals using Rentrop grade. 6. Presence or absence of bridging collaterals. TIMI Grade Flow: TIMI Grade Flow' is a scoring system from 0-3 referring to levels of coronary blood flow assessed during percutaneous coronary angioplasty: TIMI 0 flow (no perfusion) refers to the absence of any ante grade flow beyond a coronary occlusion. TIMI 1 flow (penetration without perfusion) is faint ante grade coronary flow beyond the occlusion, with incomplete filling of the distal coronary bed. TIMI 2 flow (partial reperfusion) is delayed or sluggish ante grade flow with complete filling of the distal territory. TIMI 3 is normal flow, which fills the distal coronary bed completely. Collaterals were graded by the degree of filling of the involved vessel beyond the CTO according to the Rentrop classification. Grade 0 = no visible filling. Grade 1 = side branch filling but without any dye reaching the epicardial segment. Grade 2 = partial epicardial filling. Grade 3 = complete filling of the epicardial segment. Angiographic patterns outlining the morphologic characteristics of the vessels and defining lesion specific characteristics are identified to influence the likelihood of a successful PCI. Several projections were performed in order to better visualize the coronary arteries and overcome the problem of foreshortening and superimposition of the vessels. (d) Guiding catheter selection: For the left coronary system, extra backup type guiding catheters (extra backup) were preferred and used in most cases. (e) Guide wire selection: The wires used in this study were PT2 (moderate support), Gaia Second, Pilot 50 & 150, Miracle 3 and Fielder XTA. (f) Strategies to open CTO: Antegrade approach to CTO was the strategy applied in all patients of our study. (g) After guide wire successfully cross the CTO, subsequent balloon angioplasty and stent implantation were performed with appropriate-sized devices. The first attempt to

cross the CTO with a 1.5-2.0 mm diameter, low profile balloon with a tapered tip and a lubricious coating facilitate crossing even long lesions. All successfully opened CTO were treated with DES. (h) When we stop the recanalization procedure: When a CTO is proving refractory to initial maneuvers, the operator weight the likelihood of success with continued persistence against the risk of complications developing.

Two-dimensional and Three-dimensional transthoracic and speckle tracking echocardiography (follow up study) : Reassessment of left ventricular function (LVEF%), left ventricular end-diastolic and end-systolic dimensions (LVEDd & LVESd) and also two dimensional speckle tracking (GLS) one month after successful PCI to CTO lesion.

Statistical analysis of data

Statistics were done by computer using The SPSS version 15.0 for Windows statistical software package program. The continuous variables are reported as the mean ± standard deviations (SD) and the categorical variables are expressed as percentages. A comparison of the continuous variables pre and one month after the procedure was performed using paired samples test. The GLS and velocities were compared using paired samples test. The comparison between (2D & 3D) speckle tracking pre-and post-procedure in diabetic and non-diabetic patients was performed using paired samples test. The comparison between 2D GLS pre and post procedure in patients with EF ≥ 50% and patients with EF < 50% was performed using paired samples test. The comparison between 3D LS pre-and post-procedure in patients with EF ≥ 50% and

patients with EF < 50% was performed using paired samples test. Linear correlation between 2D GLS and 3D LS was performed using person correlation test. The delta values defined as the difference between the first month and the pre-procedure value. A value of p < 0.05 was considered statistically significant.

RESULTS

Demographic data and risk factors: Age of the patients ranged from 48 to 72 years with a mean of 60.8 ± 6.2 SD years [39 males (65%) and 21 females (35%)]. Hypertension: There were 38 hypertensive patients (63.33%) and 22 non- hypertensive patients (36.67%). The study included 32 patients with diabetes (53.33%) and 28 patients were non-diabetics (46.67%). 38 patients of our study population were smokers (63.33%) and 22 patients were non- smokers (36.67%) (Table 1).

Table (1) Incidence of risk factors in the study

Risk factors	Number	Percentage
Hypertension	38	63.33%
Diabetes mellitus	32	53.33%
Smoking	38	63.33%

Echocardiographic parameters (pre and post procedure): Comparison between LVEF (%) by Simpson′s method pre and post procedure:

In pre procedure, LVEF by Simpson′s method ranged from 41% to 75% with a mean of 57.0 ± 8.7 SD (%). In post procedure, ranging from 44% to 76% with a mean of 58.5 ± 8.1 SD (%). There was significant increase in the mean LVEF % measured by 2DE (Simpson′s method) post procedure (Table 2).

Table (2): Comparison between LVEF % by Simpson′s method pre and post procedure.

Time	EF % 2D					Paired Differences		Paired Samples Test	
	Range		**Mean**	**±**	**SD**	**Mean**	**SD**	**t**	**P-value**
Pre	41	- 75	56.950	±	8.650	-1.533	1.384	-8.585	<0.001*
Post	44	- 76	58.483	±	8.081				

There was very high statistically significant comparison between LVEF % by 2 DE (Simpson′s method) pre and post procedure with a P value <0.001.

In pre procedure, LVEDd ranged from 3.3 cm to 6.8 cm with a mean of 5.5 ± 0.6 SD (cm). In post-procedure, LVEDd ranged from 3.3 cm to 6.7 cm with a mean of 5.01 ± 0.6 SD (cm). There was significant decrease in the mean LVEDd (cm) post-procedure. Highly Significant statistical comparison was seen between LVEDd (cm) pre-and post-procedure with a P value < 0.001. In pre

procedure, LVESd ranging 2.1 cm from to 5.3 cm with a mean of 3.5 ± 0.6 SD (cm). In post-procedure, LVESd ranged from 2.1 cm to 5.1 cm with a mean of 3.5 ± 0.6 SD (cm). There was significant decrease in the mean LVESd (cm) post-procedure. Significant statistical comparison was seen between LVESd (cm) pre-and post-procedure with a P value < 0.001(Figure 1).
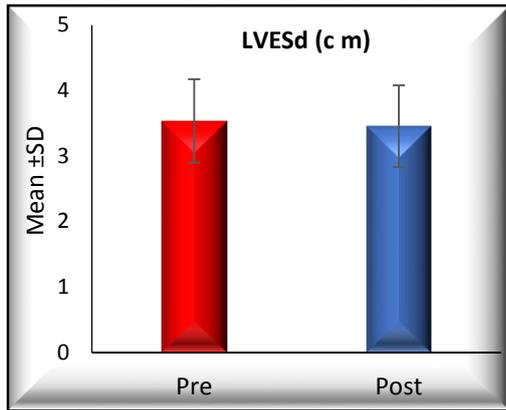
Figure (1): Comparison between LVESd (cm) pre and post procedure.

In pre procedure, 2 D Speckle tracking % ranging from -20.3 % to -10.7 % with a mean of -15.2 ± 2.6 SD (%). In post procedure, 2 D Speckle tracking ranging from -22.4 % to -11.2 % with a mean of -16.9 ± 3.0 SD (%). There was significant increase in the mean 2D Speckle post procedure. There was very high statistically significant comparison between 2D Speckle tracking % (GLS) pre and post procedure with a P value <0.001 (Figure 2).
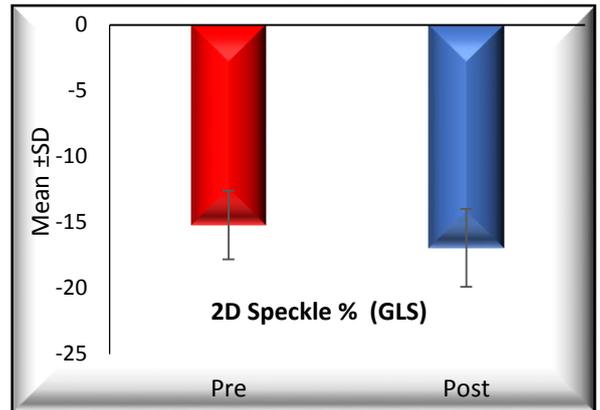
Figure (2): Comparison between 2D Speckle tracking % (GLS) pre and post procedure.

In pre procedure, LVEF (%) by 3DE ranged from 42 % to 72% with a mean of 56.9 ± 7.9 SD (%). In post procedure, LVEF (%) by 3DE ranged from 46 % to 74 % with a mean of 59.5 ± 7.7 SD (%). There was significant increase in the mean LVEF (%) by 3DE post procedure (Table 3).

Table (3): Comparison between LVEF % by 3DE pre and post procedure.

Time	EF % 3D				Paired Differences		Paired Samples Test	
	Range		Mean	±	SD	Mean	SD	T	P-value
Pre	42 - 72	56.883	±	7.876	-2.617	1.195	-16.968	<0.001*
Post	46 - 74	59.500	±	7.675				

There was very high statistically significant comparison between LVEF (%) by 3DE pre and post procedure with a P value <0.001. In pre procedure, LVEDV (ml) by 3DE ranged from 85 ml to 155 ml with a mean of 102.5 ± 12.8 SD (ml). In post procedure, LVEDV (ml) by 3DE ranged from 81 ml to 132 ml with a mean of 96.4 ± 10.5 SD (ml). There was significant decrease in the mean LVEDV (ml) by 3DE post procedure. There was very high statistically significant comparison between LVEDV (ml) by 3DE pre and post procedure with a P value <0.001. In pre procedure, LVESV (ml) by 3DE ranged from 29 ml to 90 ml with a mean of 43.6 ± 9.0 SD (ml). In post procedure, LVESV (ml) by 3DE ranged from 24 ml to 69 ml with a mean of 37.8 ± 7.4 SD (ml). There was significant decrease in the mean LVESV (ml) by 3DE post procedure. There was very high statistically significant comparison between LVEDV by 3DE pre and post procedure with a P value <0.001 (Figure 3).
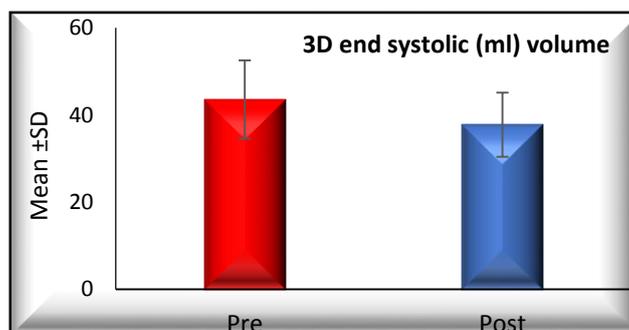
Figure (3): Comparison between LVESV(ml) by 3DE pre and post procedure.

In pre procedure, 3D Speckle tracking (%) ranged from -20 % to -11 % with a mean of -14.9 ± 2.6 SD (%). In post procedure, 3D Speckle tracking (%) ranged from -22 % to -11 % with a mean of -16.5 ± 2.8 SD (%). There was significant increase in the mean 3D Speckle tracking % (LS) post procedure. There was very high statistically significant comparison between 3D Speckle tracking % (LS) pre and post procedure with a P value <0.001 (Figure 4).
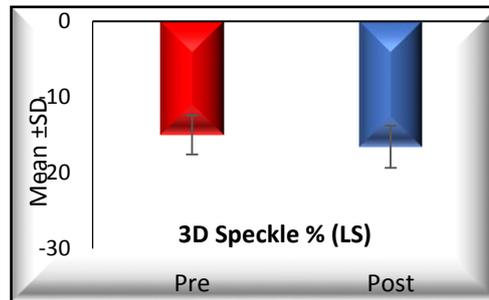
Figure (4): Comparison between 3D Speckle tracking (LS) pre and post procedure.

Multivariate analysis to detect the actual significance of individual variable in the presence of other variables: Comparison between 2D GLS % (pre and post procedure) in diabetic patients: Diabetic patients showed improvement of 2D GLS % with pre procedure mean of -14.1 ± 2.7 SD, post procedure mean of -15.4 ± 2.8 SD and mean differences of 1.4 ± 0.7 (Table 4).

Table (4): Comparison between 2D GLS % (per and post procedure) in diabetic patients.

DM (Yes)	2D Speckle % (GLS)				Paired Differences		Paired Samples Test	
	Range		Mean	± SD	Mean	SD	t	P-value
Pre	-20.1 - -10.7		-14.075	± 2.709	1.366	0.717	10.776	<0.001*
Post	-20.9 - -11.7		-15.441	± 2.781				

There was high statistically significant comparison between 2D GLS % (pre and post procedure) in diabetic patients with a P value <0.001.

Comparison between 2D GLS % (pre and post procedure) in non-diabetic patients: Non-diabetic patients showed improvement of global longitudinal strain with pre procedure mean of -16.5 ± 1.8 SD (%), post procedure mean of -18.6 ± 2.2 SD (%) and mean differences of 2.1 ± 0.8. There was high statistically significant comparison between 2D GLS % (pre-and post-procedure) in non-diabetic patients with a P value <0.001.

Comparison between 3D LS % (pre and post procedure) in diabetic patients: Diabetic patients showed improvement of 2D GLS % with pre procedure mean of -13.8 ± 2.6 SD, post procedure mean of -15.2 ± 2.6 SD and mean differences of 1.4 ± 0.8. There was high statistically significant Comparison between 3D LS % (pre -and post- procedure) in diabetic patients with a P value <0.001.

Comparison between 3D LS % (pre and post procedure) in non-diabetic patients: Non-diabetic patients showed improvement of 3D LS % with pre procedure mean of -16.3 ± 1.9 SD, post procedure mean of -18.1± 2.1 SD and mean differences of 1.8 ± 0.9. There was high statistically significant comparison between 3D LS % (pre- and post- procedure) in non-diabetic patients with a P value <0.001.

Comparison between 2D GLS (pre and post procedure) in patients with 2D EF ≥ 50 %: Patients with 2D EF ≥50 % showed improvement of 2D Speckle tracking % (GLS) with pre procedure mean of -16.1 ± 2.2 SD (%), post procedure mean of -17.9 ± 2.4 SD (%) and mean differences 1.9 ± 0.805 SD (%). There was high statistically significant comparison between 2D GLS (pre and post procedure) in patients with 2D EF ≥ 50 % with a P value <0.001.

Comparison between 2D GLS (pre and post procedure) in patients with 2D EF < 50 %: Patients with 2D EF <50 % showed improvement of 2D Speckle tracking % (GLS) with pre procedure mean of -11.8 ± 1.0SD (%), post procedure mean of -13.0± 1.0 SD (%) and mean differences 1.2 ± 0.8 SD (%). There was high statistically significant comparison between 2D GLS (pre and post procedure) in patients with 2D EF < 50 % with a P value <0.001 (Figure 5).
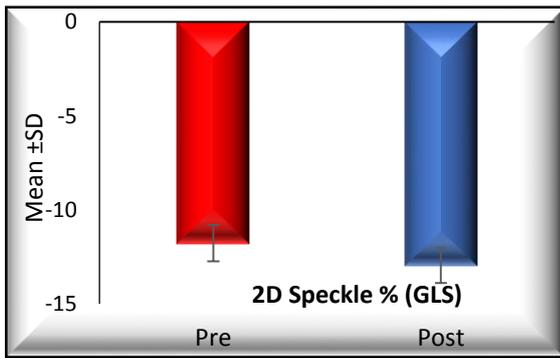
Figure (5): Comparison between 2D GLS (pre and post procedure) in patients with 2D EF < 50 %

Comparison between 3D LS (pre and post procedure) in patients with 3D EF ≥50 %

Patients with 2D EF ≥50 % showed improvement of 3D Speckle tracking % (LS) with pre procedure mean of -11.8 ± 1.0 SD (%), post procedure mean of -13.0± 1.0 SD (%) and mean differences 1.2 ± 0.8 SD (%).There was highly statistical significant comparison between 3D LS (pre and post procedure) in patients with 2D EF ≥ 50 % with a P value <0.001.

Comparison between 3D LS (pre and post procedure) in patients with 3D EF <50 %

Patients with 2D EF <50 % showed improvement of 3D Speckle tracking % (LS) with pre procedure mean of -11.6 ± 0.8 SD (%), post procedure mean of -12.7± 0.9 SD (%) and mean differences 1.2 ± 0.6 SD (%). There was highly statistical significant comparison between 3D LS (pre and post procedure) in patients with 2D EF < 50 % with a P value <0.001 (Figure 6).
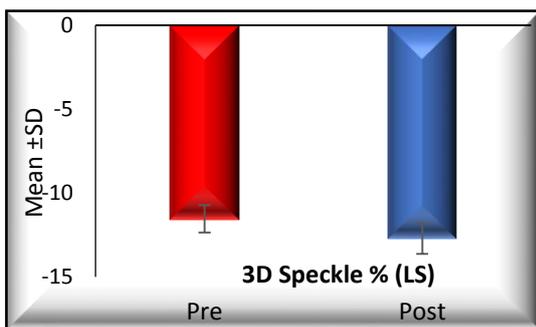
Figure (6): Comparison between 3D LS (pre and post procedure) in patients with 2D EF < 50 %

Linear correlation between 2D GLS and 3D LS:

Improvement in the 2D GLS % was correlated with an improvement in the 3D LS % (r= 0.9, P value <0.001) (Table 5) and (Figure 7).

Table (5): Linear correlation between 2D GLS % and 3D LS %

Correlations		
	2D Speckle % (GLS) Post	
	r	**P-value**
3D Speckle % (LS)Post	0.983	<0.001*
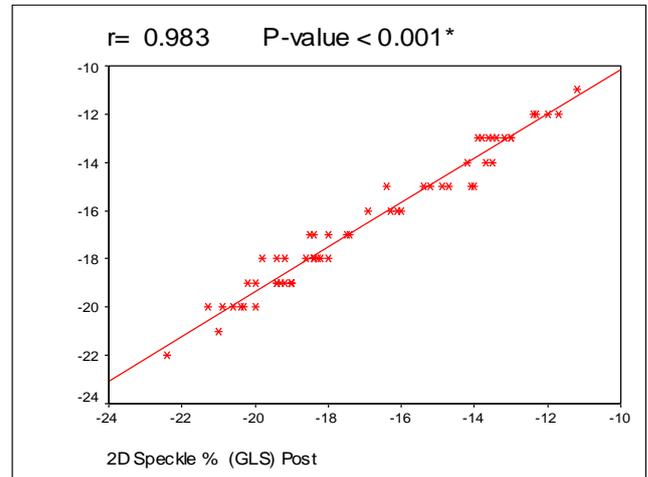
Figure (7): Linear correlation between 2D GLS % and 3D LS%

DISCUSSION

Erdogan et al. [20] were the first who studied the early benefit of revascularization of CTOs (after one month) on LV function using 2D global longitudinal strain and RT3DE. They used 2DE to assess LVEF %, LV dimensions (LVESd and LVEDd) and 2D speckle tracking (global longitudinal strain) pre- and one month after successful PCI of CTO and showed a significant increase of LVEF % and non-significant decrease in LVESd and LVEDd. The global longitudinal strain showed a significant improvement after successful revascularization. The study used 3DE to assess LVEF % and LV volume (LVESV and LVEDV) pre- and one month after successful PCI to CTO and showed a significant increase of LVEF % and also significant decrease in LVESV and LVEDV. In our study, we added another novel echocardiographic parameter to parameters that was used by **Erdogan et al**. [20]. 3D speckle tracking (longitudinal strain %) was used as a new method to assess myocardial function after PCI of a CTO. We found a significant improvement in 3D longitudinal strain after successful revascularization. In concordance with **Erdogan et al.** [20] results, we found that the mean left ventricular ejection fraction (2D and 3D) significantly increased while the left ventricular end-diastolic and end-systolic volumes significantly decreased. The global longitudinal strain (2DSTE) showed a significant improvement

after successful revascularization. In discordance with **Erdogan et al.** [20] results, we found a significant decrease in LVESd and LVEDd after successful revascularization.

In **Wang and Ren** [21] study, improvement of LVEF was observed for follow up to 3 and 6 months after percutaneous revascularization in patients with CTO. However, by 2D speckle tracking echocardiography (2D-STE), the GLS improvement was observed as early as 1 day after CTO-PCI. These results demonstrate that 2D-STE is a reliable way to monitor early subclinical LV changes.

In the present study, our results were similar to those reported by **Baks et al.** [22] who showed the beneficial effect of successful CTO revascularization on the end-systolic and end-diastolic volumes by 3DE. They showed that the extent of dysfunctional but viable myocardium before revascularization was related to an improvement in the end systolic volume and LVEF. Some studies showed that LV volume changes after MI depended on the patency status of the infarct-related artery. When the infarct-related artery was totally occluded, a significant increase in both end-diastolic and end-systolic volumes occurred, with a resulting decrease in EF [25].

In the present study, we found a reduction in LV volumes; however, we used RT3DE, which is more robust than 2DE. **Cheng et al.** [23] used contrast-enhanced MRI to demonstrate that improved LV function and attenuated LV remodeling occurred after successful CTO PCI if the vessel patency is maintained. In another study, which used magnetic resonance imaging, early and late improvements in regional myocardial function were observed in the territory of the occlusion **Kirschbaum et al.** [24] and **Bondarenko et al.** [25] they showed the functional recovery after revascularization of hibernating myocardium on 35 patients using contrast enhanced CMR. Functional myocardial recovery started at 3-6 months with continuing improvement up to 24 months, suggesting that recovery of systolic function can be further delayed up to 24 months especially in myocardial segments with higher extent of hyper enhancement.

The improvements in LVEF % and myocardial function in our study, based on 2DSTE, 3DSTE and RT3DE are consistent with the results of **Cheng et al.** [23].

The improvements in the LVEF and GLS observed in the current study may be the result of recovered hibernating myocardium. Multiple retrospective studies showed the potential benefit of PCI in patients with CTO. Successful treatment improves LV function [30]. In a study by **Ermis et al.** [26] coronary intervention had a positive impact on both global and regional left ventricular function in patients with chronic coronary artery occlusion. Our results were similar to those reported by **Uslu et al.** [27] who showed a significant decrease in LVEDd and LVESd after PCI with significant increase in EF % (two months after the procedure). However, in our study the assessment was one month after the procedure.

Magdy et al. [28] study showed a significant reduction in LVEDd and LVESd after PCI of CTO (3 months after the procedure) and showed highly significant increase in LVEF % after successful recanalization of CTO (3 months after the procedure).

Our results were similar to these results but the assessment of LVEDd, LVESd and LVEF % in our study was one month after the procedure. In the present study, our results were in concordance with **Megaly et al.** [29] meta-analysis of 34 studies, which demonstrated that successful CTO PCI is associated with statistically significant increase in mean LVEF by 3.8% during a mean follow-up duration of 7.9 months.

This improvement was consistent in further sensitivity and subgroup analyses. Furthermore, successful CTO PCI was associated with statistically significant reduction in LVESV indicating an improvement in LV remodeling. A previous meta-analysis of 34 studies with 2310 patients on the impact of CTO PCI on LV size and function that was performed by **Hoebers et al.** [30] showed a statistically significant increase in LVEF (4.44%) and decrease in LVEDV index (6.14 mL/m^2) as compared to baseline.

Nakamura et al. [31] reported that ejection fraction results of a 5-center Asian registry, in which 88 patients with successfully recanalized CTOs were treated with DES, was significantly improved in these patients on follow up. our results were in concordance with **Elena et al.** [32] that showed successful revascularization of CTO improves regional systolic function determined by WMSI and decreases angina. LS of treated segments and infarct size tend to decrease after procedure, with no change in global measures of cardiac function. **El Shafey et al.** [33] study showed improvement in regional and global LV function measured by PW-TDI in patients with CTO vessel after successful recanalization by PCI.

Patients with DM have a greater extent of CAD and are prone to impaired clinical outcomes compared with non-diabetic patients. A previous observational study about CTO PCI in diabetics was performed by **Safley et al.** [34] where they reported

that DM patients do not seem to have the same survival benefits from successful PCI of a CTO as patients without DM. In our study, both patients with LVEF ≥ 50% and LVEF < 50% displayed significant improvement in the 2D GLS and 3D LS. In addition, diabetic and non-diabetic patients displayed significant improvement in the 2D GLS and 3D LS. In our study, we found that the improvement in the 2D GLS was correlated with an improvement in the 3D LS. So, use of 3D LS is useful in assessment of global LV function and to detect the improvement of LVEF % after successful CTO PCI.

CONCLUSION

By using novel echocardiographic techniques, our results showed that restoring the coronary blood flow in chronic total occlusion patients reduces the left ventricular volumes and dimensions, improves the left ventricular ejection fraction also improves the 2D global longitudinal strain and 3D longitudinal strain of hibernating myocardium.

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