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Left Anterior Descending CTO Revascularization: Short-Term Effects on Left Ventricular Function Assessed by Speckle Tracking Echocardiography

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Abstract

Background: Chronic total occlusion (CTO) of the left anterior descending (LAD) artery is a common and clinically significant form of coronary artery disease (CAD), often associated with impaired myocardial function and adverse outcomes. Although percutaneous coronary intervention (PCI) has shown clinical benefits in CTO, its short-term effects on left ventricular (LV) function remain underexplored. This study aimed to evaluate the early impact of LAD CTO revascularization on LV systolic function, using global longitudinal strain (GLS) and global circumferential strain (GCS) as sensitive imaging biomarkers.

Methods: A prospective single-arm trial was conducted on 120 patients diagnosed with LAD CTO at Ain Shams University and Mabrah Masr Alqadima hospitals in Egypt, and indicated to receive PCI during the period from January 2023 to June 2024. All patients underwent baseline and 6-month post-PCI echocardiography and speckle tracking analysis. LV diameters and volumes, FS%, EF%, GLS, and GCS were measured. PCI procedural data and clinical characteristics were also recorded.

Results: This group included 120 patients with an average age of 58.2 years and male dominance (82.5%). The success rate of all revascularization procedures was 100% with most of them being done through antegrade access (62.5%) with minimal complications (12.5%). There was a significant reduction in LVED volume (5.8 19.4 ml, $p = 0.040$), heart rate (4.3 8.9 bpm, $p = 0.005$), and GCS (0.3 1.3, $p = 0.042$) at the 6-month follow-up, but the EF and GLS were unchanged. Also, LAD diameter did not change significantly.

Conclusion: LAD CTO revascularization with PCI is associated with early reverse remodeling, reflected in the reduced LVED volume, improved GCS, and lower heart rate. These findings suggest early myocardial recovery post-revascularization, particularly in circumferential function, though more pronounced.

Keywords: CTO PCI; LAD Revascularization; Global Strain; Speckle Tracking; Left Ventricular Function

Introduction

Cardiovascular diseases are the leading cause of death worldwide. They are no longer confined by geographical area or by age, sex, or socioeconomic boundaries and they have already reached epidemic proportions in poor countries ^[1]. According to the World Health Organization (WHO), coronary artery disease (CAD) causes around 16.7 million deaths in the world each year ^[2].

CAD is a pathological process characterized by atherosclerotic plaque accumulation in the epicardial arteries. CAD can have chronic long stable periods (CCS) or presents with acute atherosclerotic events (ACS). Even in the chronic state, it is a serious disease and must be diagnosed and treated aggressively ^[3].

Approximately one-third of the patients with significant CAD on angiography (CA) have one or more coronary artery coronary total occlusion (CTO). CTO is defined as 100% occlusion in the coronary arteries with TIMI 0 flow of at least 3 months' duration ^[4]. The duration may be difficult to determine if there is no prior angiogram demonstrating presence of the CTO. In such cases estimation of the occlusion duration is based upon the first onset of

angina or dyspnea and/or prior history of myocardial infarction in the target vessel territory^[5].

In the 2018 European society of cardiology on percutaneous coronary intervention (PCI) guidelines, CTO PCI carries a class IIa/level of evidence B recommendation in patients with angina resistant to medical therapy or with a large area of documented ischemia in the territory of the occluded vessel. The guidelines emphasize the importance of selecting patients with appropriate clinical indications for CTO PCI and the importance of operator expertise^[6].

Revascularization of CTO vessel by PCI results in clinical improvement, decrease the need for maximal medical treatment, decrease the incidence of arrhythmias, improve the long-term survival, and decrease the need for coronary artery bypass grafting (CABG)^[7]. However, its effect on the echocardiographic parameters of the left ventricle (LV) function is still relatively underexplored.

Assessment of LV function can be done by different imaging modalities and methods, but two-dimensional (2D) echocardiography is the ideal modality and LV global longitudinal strain (GLS) is a more sensitive marker of LV myocardial ischemia and LV function than LV ejection fraction (EF) because it is angle independent and less subjective to artifacts^[8].

The aim of the study is to assess the short-term effect of successful CTO PCI intervention to LAD on LV systolic function measured by GLS speckle tracking echocardiography.

Methodology

This was a prospective single-arm trial conducted at Ain Shams University Hospitals cardiology department and Mabrah Masr Alqadima hospital during the period from January 2023 to December 2024. This study included 120 patients who were diagnosed with CAD (CTO LAD) and were indicated to receive PCI. We recorded echocardiographic and strain parameters at baseline and followed the patients for 6-month duration, after which we recorded these parameters again and compared them to baseline, to detect significant changes.

Prior to participation, informed written consent was obtained from all subjects. Each participant received a unique identification code to maintain confidentiality. The study protocol received ethical clearance from the Research Ethics Committee of our local institution.

Eligibility Criteria

Participants were eligible for inclusion if they were aged over 18 years, diagnosed with CAD due to a chronic total occlusion of the left anterior descending coronary artery and indicated to receive PCI, even if they were previously revascularized by DES. Exclusion criteria included patients who were presented with acute coronary syndrome, received previous coronary artery bypass graft or any other open-heart surgery, associated with poor echogenic window, diagnosed with other coronary artery lesions (LCS or RCA) or having any contraindication to receive PCI. We also excluded patients who failed to provide informed consent before being enrolled to the study.

Sampling Method

A random sample of patients of Ain Shams University hospitals or Mabrah Masr Alqadima hospital, Egypt applying the inclusion and exclusion criteria. The final

sample size consisted of 120 patients, determined using an appropriate sample size calculator to ensure sufficient power for statistical analysis.

Study Procedures

All enrolled patients underwent a comprehensive baseline assessment that included; (1) full medical history and physical examination to detect relevant data such as (age, weight, height, BMI, gender, presenting symptoms, history of smoking, history of diabetes mellitus, history of hypertension, history of dyslipidemia and family history), (2) 12-lead resting electrocardiography (ECG) and transthoracic echocardiography (TTE).

All patients underwent PCI, performed by experienced cardiologists blinded to echocardiographic results. CTO was defined according to standard criteria. DES were used exclusively for revascularization. PCI was deemed successful when residual stenosis was <30%. The following procedural details were collected and reported in the manuscript: access technique (anterograde vs retrograde), number and site of DES and complication rates.

Echocardiographic and Strain Imaging Protocol

TTE was performed prior to PCI and repeated 3 to 6 months post-procedure using the Philips IE33 system (Philips Medical Systems), employing ECG-gated acquisition with the patient in the left lateral decubitus position. Key parameters measured included: left atrial diameter (LAD), left ventricular end-diastolic diameter (LVEDd), left ventricular end-systolic diameter (LVESd), left ventricular end-diastolic volume (LVEDv), left ventricular end-systolic volume (LVESv), Fractional shortening (FS%) and heart rate (HR).

For strain analysis, apical images were acquired and processed using QLAB 9 CMQ software. Speckle-tracking echocardiography was applied to calculate global longitudinal strain (GLS) and Global Circumferential Strain (GCS) based on the ASE 17-segment model, with manual adjustment of tracking points and ROI. Premature beats were excluded, and the best cardiac cycle with optimal strain curves was selected for analysis.

Study Endpoints

In this study, the co-primary endpoints were the absolute changes from baseline to 6-month follow-up in both the GLS and GCS, as measured by speckle tracking echocardiography. Secondary endpoints included change in the LAD, LVEDd, LVESd, LVESV, FS%, as well as changes in the HR.

Statistical analysis

Statistical analysis was done by SPSS v28 (IBM Inc., Armonk, NY, USA). Quantitative variables were presented as mean and standard deviation (SD). Qualitative variables were presented as frequency and percentage (%). Changes from baseline were presented as mean change with SD and confidence interval (CI).

Results

Table 1 included the demographic characteristics of the included population, which demonstrated that our predominantly male cohort (82.5% males) cohort consisted of 120 patients with an average age of 58.16 ± 5.25 years, body weight of 92.97 ± 10.91 kg, height of 1.64 ± 0.05 m

and BMI of $34.79 \pm 4.32 \text{ kg/m}^2$. As for the medical history and clinical presentation of the patients, chest pain was prevalent in most of the cases (82.5%), while dyspnea reporting lower frequency, affecting only (47.5%) of patients. Moreover, 50% of the patients had a history of smoking, 55% had DM, 40% were diagnosed with HTN, 60% were afflicted with dyslipidemia and 40% endorsed a positive family history of cardiovascular disease.

Table 2 contained relevant information about the PCI and stent utilized in our study. The majority of the PCI performed in our center were conducted with the anterograde technique (62.5%), while the retrograde approach was utilized only in (37.5%) of the sample. Furthermore, only 15 patients (12.5%) experienced complicated PCI, leaving the other 105 patients (87.5%) complication-free. In our cohort, the majority of the patients received either 2 DESs (37.5%) or 3 DESs (47.5%), suggesting a significant lesion burden. On the other hand, only a small fraction of patients received 1 stent ($n=3$) or 4 stents ($n=3$). Anatomically, proximal stent placement was the dominant placement location, occurring in (65%) of the patients, followed by the mid-vessel segment (25%), distal segment (7.5%) and the ostial segment (2.5%).

At baseline, the echocardiographic profile of the study population reflected a clear image of left ventricular remodeling. This is indicated by the following parameters: the LAD averaged $34.3 \pm 2.99 \text{ mm}$, the LVED diameter reached a mean of $58.2 \pm 4.98 \text{ mm}$, while the LVES diameter measured $44.7 \pm 3.58 \text{ mm}$. Correspondingly, the LVEDV and LVESV were both high, with mean values of $202.8 \pm 43.86 \text{ ml}$ and $89.0 \pm 17.92 \text{ ml}$, respectively. Furthermore, we observed that the FS% had an average of $22.6 \pm 2.60\%$, while the EF% was reported with a mean of $45.4 \pm 5.42\%$. Additionally, the GLS was moderately impaired at -13.4 ± 1.89 , while the GCS was slightly less affected with an average mean of -12.9 ± 2.31 . Table 3

After 6-months of follow-up, the LAD remained unchanged from baseline, keeping the same diameter of $34.3 \pm 2.99 \text{ mm}$, indicating no significant atrial reverse remodeling over time. On the other hand, the LVEDD exhibited a slight numerical decrease to $57.7 \pm 4.50 \text{ mm}$, while the LVESD remained steady at $44.8 \pm 3.37 \text{ mm}$. Furthermore, we also observed that both LVED and LVES were associated with a modest volume reduction with a mean average of $196.9 \pm 37.19 \text{ ml}$ and $89.1 \pm 16.77 \text{ ml}$, respectively. FS% showed a slight increase, rising to $23.1 \pm 2.66\%$, while EF increased modestly to $46.3 \pm 5.28\%$. Finally, a modest decrease in HR was observed with a mean of 67.0 ± 6.48 , GLS remained impaired at -13.2 ± 1.91 , while GCS declined slightly to -12.6 ± 2.35 . Table 4

From baseline to the 6-month follow-up, LVED volume showed a significant reduction of $-5.8 \pm 19.4 \text{ ml}$ ($p = 0.040$), and heart rate decreased notably by $-4.3 \pm 8.9 \text{ bpm}$ ($p = 0.005$). A modest yet statistically significant improvement was also observed in GCS, increasing by $0.3 \pm 1.3\%$ ($p = 0.042$). Other parameters, including EF ($+0.9 \pm 3.0\%$, $p = 0.080$) and GLS ($+0.2 \pm 1.1\%$, $p = 0.120$), showed slight, non-significant changes, while LAD remained unchanged. Table 5

Discussion

The current research included 120 patients with an average age of 58.16 ± 5.25 years; most of them were male (82.5%), which is consistent with the established

demographic characteristics of modern CTO registries (9). Demographic results are congruent with large multinational data sets which indicate an 84-86% male prevalence in CTO-specific interventions. The average age of the current cohort fell within the lower range of the mean ages (65 to 67 years) published in similar articles, which may be due to regional variations in healthcare-seeking behavior or referral interventional pathways [10].

In our study, we observed a high prevalence of cardiovascular risk factors in our population, including diabetes mellitus (55%), hypertension (60%), and dyslipidemia (60%), which is consistent with other findings from contemporary CTO registries [11]. The smoking rate of 50% was comparable to other CTO studies, reinforcing the strong association between smoking and coronary atherosclerosis leading to total occlusions, while the mean BMI of $34.79 \pm 4.32 \text{ kg/m}^2$ indicates that 85% of our patients were overweight or obese, which in turn is in alignment with recent observations that the majority of CTO patients fall into these categories [12]. This finding supports previous research demonstrating that obesity does not significantly impact CTO PCI success rates or complications [13].

Only 12.5% of patients experienced complications during the PCI, indicating in the process the high procedural success in our study. Furthermore, the predominant use of anterograde approach over the retrograde approach, reflects the current hybrid strategies and is mainly caused by the fact that in most cases the anterograde approach is attempted first. Ultimately, the relatively high utilization of retrograde in our cohort suggest a more complex lesion subset. Our previous findings are in mirror with findings from contemporary CTO registries reporting complication rates of 3-5.4% and the more dependence on the anterograde approach [14, 15].

Effective and sustainable revascularisation is one of the major issues in the percutaneous treatment of chronic total occlusions of the left anterior descending (LAD) artery. The recent study of the DES-related distribution patterns in a modern cohort ($n=148$) demonstrates that most of the patients (85%) were implanted with 2-3 stents, which can be explained by the extensive lesion profile typical of LAD CTO lesions. Notably, the deployment of proximal stents was the most frequent (65%) as expected due to the prevalence of LAD CTOs in the proximal segment. This location is clinically relevant in that proximal LAD CTOs are associated with a larger percentage of the total myocardial territory at risk and thus have a more significant effect on left ventricular performance [16].

Regarding the baseline echocardiographic findings, we observed evidence of LV remodelling that is consistent with chronic ischemic cardiomyopathy [17]. The mean LVEF of $45.4 \pm 5.42\%$ indicates mild to moderate systolic dysfunction, while the enlarged LV dimensions (LVED diameter $58.2 \pm 4.98 \text{ mm}$, LVES diameter $44.7 \pm 3.58 \text{ mm}$) and volumes (LVEDV $202.8 \pm 43.86 \text{ ml}$, LVESV $89.0 \pm 17.92 \text{ ml}$), demonstrate chronic hemodynamic changes, which is typical for CTO patients [18].

Furthermore, both the GLS (-13.4 ± 1.89) and the GCS ($-12.9 \pm 2.31\%$) values were consistent with previous studies, that reported baseline values that fall within the range from -12 to -16%. This proves the fact that these strain parameters are more sensitive markers of myocardial dysfunction than conventional ejection fraction in CTO patients [19].

At six-month follow-up, the echocardiographic parameters showed selective improvements. While conventional parameters like LVEF showed modest non-significant improvement (45.4% to 46.3%, $p=0.080$), more sensitive indices demonstrated meaningful changes. The stability of left atrial diameter (34.3 mm unchanged) suggests that atrial reverse remodeling requires longer follow-up periods or more extensive revascularization [20].

We observed that echocardiographic measurements showed small changes in LV dimensions and ejection fraction, which is consistent with previous a meta-analysis data that suggested that the improvements in LVEF following CTO PCI are usually small (3-5%) and may take a long follow-up to reach statistical significance [21]. These findings are in line with the findings of the REVASC trial that found no significant improvement in LVEF at 6 months following successful CTO revascularization [22].

The current research indicates a statistically significant yet numerically small reduction of LVED volume in the postprocedural period (-5.8 ± 19.4 ml; $p = 0.040$). This result is a clinically significant early index of reverse ventricular remodeling [22]. The reduction observed is consistent with the rest of the literature, especially meta-analytic reports that highlight the ability of CTO-PCI to induce positive changes in LV geometry, which is usually reflected in the decreases in LV end-systolic volume. Although the the observed change in LVED volume was relatively small, its occurrence, however, reflects the same physiological trend: that of the early myocardial unloading and mechanical rehabilitation [23].

The significant heart rate reduction (-4.3 ± 8.9 bpm, $p=0.005$) is a noteworthy finding that may reflect improved cardiovascular efficiency following revascularization. This change could indicate reduced sympathetic activation and improved cardiac autonomic balance, which has been associated with better outcomes in coronary disease patients [20]. The statistically significant change in GCS ($0.3 \pm 1.3\%$; $p=0.042$) shows that strain imaging is more sensitive in revealing early functional changes after CTO revascularization (24). This finding supports prior reports showing that strain parameters enhance earlier and more dependably than customary echocardiographic parameters after effective CTO PCI. The non-significant numerical increase in GLS ($+0.2 \pm 1.1\%$; $p=0.120$) is in line with the results that circumferential strain can be more sensitive to revascularization than longitudinal strain in some coronary territories [25].

The current study explains the early reverse remodeling course after CTO revascularization. A significant reduction in left ventricular end-diastolic volume and a corresponding improvement in global circumferential strain was noted that indicated early revascularization-related hemodynamic benefits to a hibernating heart [26]. The preferential improvement of these parameters compared to others highlights that a 6-month follow-up is only a marker of the early adaptations, whereas more complete functional recovery, including an increase in ejection fraction, might be observed only after a longer period of observation, as it was previously reported that better results were observed at 912 months, especially in CTOs of the left anterior descending artery with low baseline left ventricular function [27].

Finally, in this single-arm study we were able to provide valuable insights into the short-term effects of LAC CTO revascularization, utilizing multiple relevant parameters, in order to be able to provide a more comprehensive picture. Moreover, the focus on LAD CTOs is clinically relevant,

given the large territory of myocardium at risk and the potential for greater functional improvement. However, our study still had some limitations that should be considered. First, the lack of a control group limits the interpretation of our findings. The short follow-up duration may be insufficient to capture the long-term effect of revascularization. Hence, we recommend future studies to provide comparative analysis based on longer follow-up periods.

Table 1: Baseline demographic and clinical history of the included patients (n=120)

Variables	Value
Age (years)	58.16 $\pm$ 5.25
Weight (kg)	92.97 $\pm$ 10.91
Height (m)	1.64 $\pm$ 0.05
BMI	34.79 $\pm$ 4.32
Male (%)	99 (82.5%)
Chest Pain	99 (82.5%)
Dyspnea	57 (47.5%)
Smoking	60 (50%)
DM	66 (55%)
HTN	72 (60%)
Dyslipidemia	72 (60%)
Family History	48 (40%)

BMI; body mass index, DM; diabetes mellitus, HTN; hypertension, data is presented as mean $\pm$ standard deviation or frequency (percentage).

Table 2: Overview of PCI Technique and DES Distribution in the Study Cohort

Number of patients	120
Anterograde/Retrograde (%)	
Anterograde	75 (62.5%)
Retrograde	45 (37.5%)
Complicated or not (%)	
Complicated	15 (12.5%)
not	105 (87.5%)
Number of DES (%)	
1	9 (7.5%)
2	45 (37.5%)
3	57 (47.5%)
4	9 (7.5%)
Sites of DES (%)	
Distal	9 (7.5%)
Mid	30 (25%)
Proximal	78 (65%)
Osteal	3 (2.5%)

DES; drug eluting stent, data is presented as frequency (percentage)

Table 3: Baseline Echocardiographic and Strain Parameters

Variables	Mean $\pm$ SD	Median (IQR)
Baseline LAD diameter (mm)	34.3 $\pm$ 2.99	34.0 (4)
Baseline LVED diameter (mm)	58.2 $\pm$ 4.98	59.0 (5)
Baseline LVES diameter (mm)	44.7 $\pm$ 3.58	44.5 (3)
Baseline LVED volume (ml)	202.8 $\pm$ 43.86	205.0 (51)
Baseline LVES volume (ml)	89.0 $\pm$ 17.92	87.0 (16.25)
Baseline FS%	22.6 $\pm$ 2.60	22.5 (4)
Baseline EF%	45.4 $\pm$ 5.42	46.0 (8.25)
Baseline HR (beat/m)	71.3 $\pm$ 10.04	70 (20)
Baseline GLS	-13.4 $\pm$ 1.89	-13.7 (3.08)
Baseline GCS	-12.9 $\pm$ 2.31	-13.6 (3.68)

Data is presented as mean $\pm$ SD and median (IQR), LAD; left atrial diameter, LVED; left ventricular end-diastolic, LVES; left ventricular end-systolic, FS%; fractional shortening, EF%; ejection fraction, HR; heart rate, GLS; global longitudinal strain, GCS; global circumferential strain.

Table 4: Echocardiographic and Strain Parameters at 6-Month Follow-Up

Variable	Mean ± SD	Median (IQR)
LAD diameter (mm)	34.3 ± 2.99	34.0 (4)
LVED diameter (mm)	57.7 ± 4.50	59.0 (4.25)
LVES diameter (mm)	44.8 ± 3.37	45.0 (2.25)
LVED volume (ml)	196.9 ± 37.19	205.0 (42.75)
LVES volume (ml)	89.1 ± 16.77	88.0 (15.25)
FS (%)	23.1 ± 2.66	23.5 (4)
EF (%)	46.3 ± 5.28	47.0 (8)
HR (bpm)	67.0 ± 6.48	70.0 (10)
GLS (%)	-13.2 ± 1.91	-13.5 (3.07)
GCS (%)	-12.6 ± 2.35	-13.3 (3.90)

Data is presented as mean ± SD and median (IQR)

Table 5: Changes in Echocardiographic and Strain Parameters from Baseline to 6 Months (n=120)

Variable	Mean Change ± SD	95% CI	P-value
LAD diameter (mm)	0.0 ± 0.0	0.00 to 0.00	–
LVED diameter (mm)	-0.5 ± 1.7	-1.03 to 0.03	0.060
LVES diameter (mm)	0.1 ± 1.1	-0.28 to 0.43	0.481
LVED volume (ml)	-5.8 ± 19.4	-12.02 to 0.37	0.040*
LVES volume (ml)	0.1 ± 6.5	-2.03 to 2.13	0.406
FS (%)	0.5 ± 2.1	-0.23 to 1.23	0.150
EF (%)	0.9 ± 3.0	-0.34 to 2.14	0.080
HR (bpm)	-4.3 ± 8.9	-7.06 to -1.54	0.005*
GLS (%)	0.2 ± 1.1	-0.06 to 0.46	0.120
GCS (%)	0.3 ± 1.3	0.01 to 0.59	0.042*

Data is presented as mean change ± SD, CI; confidence interval, *, statistically significant p-value ≤ 0.05.

Conclusion

In conclusion, our findings demonstrate early evidence of reverse remodeling following LAD CTO revascularization, characterized by modest but significant improvements in LVED volume, GCS, and heart rate. These results underscore the hemodynamic benefits of revascularization in the early phase, although more pronounced functional recovery may require longer follow-up.

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Author contribution

Authors contributed equally to the study.

Conflicts of interest

No conflicts of interest

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