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Article

The Impact of Percutaneous Coronary Intervention on Echocardiographic Parameters in Patients with Chronic Total Occlusion of the Coronary Arteries with Diverse Left Ventricular Ejection Fractions: A Single-Center Retrospective Study

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Abstract

Background: Chronic total occlusion (CTO) of the coronary arteries presents a significant challenge in the management of coronary artery disease, with diverse clinical manifestations and implications for patients with varying left ventricular ejection fraction (LVEF). The aim of this study is to investigate the impact of percutaneous coronary intervention (PCI) on echocardiographic parameters in patients with CTO and different LVEF, so as to optimize the care and outcomes of patients. **Methods**: We selected patients with CTO of coronary arteries treated at our hospital from June 2021 to June 2023 consecutively in this study. The patients were divided into two groups based on their LVEF: the low to moderate LVEF (<50%) group and the high LVEF group. Echocardiographic parameters, medication use, and demographic characteristics were assessed before and after PCI. Statistical analyses were conducted to compare changes in LVEF, left ventricular end-systolic volume (LVESV), left ventricular end-diastolic volume (LVEDV), global longitudinal strain (GLS), and left ventricular wall motion score (LVWMS) between the two LVEF groups. **Results**: A total of 100 patients including 67 patients with Low & Mid-range LVEF and 33 patients with High LVEF were included. Patients in the low and mid-range LVEF group demonstrated significant improvements in LVEF (p = 0.010), LVESV (p = 0.013), LVEDV (p = 0.034), GLS (p = 0.014), and LVWMS (p = 0.014) following PCI. In contrast, no significant changes in these parameters were observed in the high LVEF group after PCI. **Conclusion**: This study demonstrates that PCI leads to significant improvements in LVEF, LVESV, LVEDV, GLS, and LVWMS in patients with low to moderate LVEF, indicating potential benefits of revascularization in this patient subset.

Keywords

echocardiographic parameters; chronic total occlusion; coronary arteries; left ventricular ejection fractions; PCI

Introduction

Chronic total occlusion (CTO) of the coronary arteries poses a formidable challenge in the management of coronary artery disease (CAD), contributing to significant morbidity and mortality [1,2]. Patients with CTO often present with a spectrum of clinical manifestations, including angina, dyspnea, and compromised left ventricular function, leading to impaired quality of life and increased cardiovascular risk [3]. In recent years, percutaneous coronary intervention (PCI) has emerged as a pivotal therapeutic strategy for revascularization in this patient population, aiming to relieve symptoms, improve cardiac function, and enhance clinical outcomes [4,5]. While the benefits of PCI in patients with CTO have been extensively studied, the impact of revascularization on echocardiographic parameters in patients with diverse left ventricular ejection fractions (LVEF) following PCI treatment remains an area of active investigation [6,7].

Patients with CTO and varying LVEF represent a heterogeneous population, characterized by differences in underlying cardiac function, myocardial remodeling, and ischemic burden. Understanding how PCI influences echocardiographic parameters, such as LVEF, left ventricular volumes, global longitudinal strain (GLS), and left ventricular wall motion score (LVWMS), in patients with diverse LVEF can offer valuable insights into the myocardial response to revascularization and provide guidance for tailored treatment approaches. Clarifying the nuanced changes in echocardiographic indices following PCI in patients with CTO and different LVEF categories can aid in risk stratification, prognostication, and therapeutic decision-making, ultimately optimizing patient care and outcomes [8,9].

This single-center retrospective study sought to address this knowledge gap by examining the echocardiographic parameters in patients with CTO of the coronary arteries and diverse LVEF following PCI treatment, whose innovative aspect lay in its focus on evaluating the impact of PCI on echocardiographic parameters in patients with CTO and diverse LVEF. By assessing the changes in these echocardiographic parameters before and after PCI in patients with CTO and varying LVEF, the study aimed to delineate the differential myocardial responses to revascularization and offer insights into the potential benefits of PCI in these distinct patient subsets.

While previous research has explored the benefits of PCI in patients with CTO, the specific examination of myocardial responses to revascularization in distinct LVEF categories represents a novel contribution to the existing literature. By understanding how PCI influences echocardiographic parameters, such as LVEF, LVESV, left ventricular end-diastolic volume (LVEDV), GLS, and LVWMS, in patients with diverse LVEF, this study could offer a unique perspective on the myocardial response to revascularization. This innovative approach may provide valuable insights into potential differences in outcomes based on baseline LVEF and contributes to the optimization of patient care and outcomes. Therefore, while previous studies have assessed the benefits of PCI in CTO patients, the specific focus on the differential myocardial responses to revascularization in patients with varying LVEF represents a novel and important aspect of this research.

Materials and Methods

Study Design

This study was a retrospective cohort study. We selected patients with CTO of coronary arteries treated at our hospital from June 2021 to June 2023. Referring to the classification of LVEF in the relevant literature [10,11], the patients were divided into two groups based on their LVEF: the low to moderate LVEF ($<$50%) group (n = 67) and the high LVEF ($\geq$50%) group (n = 33).

Eligibility and Grouping Criteria

Inclusion criteria [12]: (1) Patients meeting the diagnostic criteria for CTO of the coronary arteries [12]; (2) Coronary angiography showing complete occlusion of one or more vessels; (3) Age $\geq$18 years; (4) Normal mental and cognitive function; (5) Complete medical records.

Exclusion criteria: (1) Recent myocardial infarction, valvular heart disease, hypertrophic cardiomyopathy, cardiogenic shock, congenital heart disease and large vessel disease, etc.; (2) History of coronary artery revascularization; (3) Coexisting malignant tumors; (4) Concurrent infectious or immunological diseases; (5) Severe hepatic or renal dysfunction or coagulation abnormalities; (6) History of cardiac surgery; (7) Intolerance to transthoracic echocardiography.

Treatment Approach

All patients received standard treatment for coronary heart disease upon admission, including antiplatelet drugs such as clopidogrel, aspirin, statins, diuretics, vasodilators, and other treatments. The patients underwent PCI via the right femoral artery route, performed by the same surgical team at our hospital. After the procedure, routine intensified antiplatelet therapy was administered, including a 6 mL/h infusion of tirofiban via intravenous pump for 48 to 72 hours, and clopidogrel 75 mg once daily, with dosage adjustment after 2 to 4 weeks, for a minimum of 24 months, in addition to lifelong use of enteric-coated aspirin 100 mg/day.

Data Collection

General Information

Patient general information was obtained through a systematic review of medical records, including age, gender, Body Mass Index (BMI), hypertension, diabetes, hyperlipidemia, current smoking status, alcohol consumption, family history of CAD, chronic lung disease, chronic kidney disease, weekly physical activity, dietary habits, sleep duration, severity of CAD, previous clinical manifestations, CTO position, preoperative medication, postoperative improvement in NYHA functional classification, improvement in 6-minute walking distance, and readmission rates. The 6-minute walk test (6MWT): Upon obtaining patient consent, the 6MWT was conducted in a 50-meter long corridor within the cardiology department to measure the distance covered within 6 minutes.

SYNTAX Score

The vascular imaging results of each CAD patient were analyzed, and the SYNTAX score was calculated using the website (syntaxscore.com). The SYNTAX score divides the coronary arteries into 16 segments, categorizing them into scores for the extent of stenosis (severe lesion or total occlusion) and scores for lesion characteristics (left main coronary artery lesion, severe vessel tortuosity, lesion length $>$20 mm, severe calcification, thrombus, "diffuse disease"/small vessels, etc.). The score for the extent of stenosis was the sum of the products of the weights of each lesion segment and the corresponding degree of stenosis, while the score for lesion characteristics was the sum of the adverse characteristic scores for each lesion. The SYNTAX score was the sum of these two components. The SYNTAX score is a new angiographic tool that can quantify the degree of atherosclerosis in the entire coronary arterial tree, including the culprit lesions. This score can aid in the preprocedural risk stratification of patients with complex CTO lesions treated via modern PCI strategies [13].

Table 1. Basic demographic and clinical characteristics.

Parameter	Low & Mid-range LVEF (n = 67)	High LVEF (n = 33)	t/χ^2	*p* value
Age (years)	63.45 ± 8.76	58.98 ± 9.24	2.356	0.020
Gender (Male)	47 (70.15%)	22 (66.67%)	0.125	0.723
BMI (kg/m^2)	24.89 ± 3.32	26.47 ± 3.88	2.115	0.037
Hypertension	16 (23.88%)	8 (24.24%)	0.002	0.968
Diabetes Mellitus	15 (22.39%)	6 (18.18%)	0.236	0.627
Hyperlipidemia	57 (85.07%)	26 (78.79%)	0.619	0.431
Smoking status (Current)	21 (31.34%)	7 (21.21%)	1.126	0.289
Alcohol consumption (Regular)	15 (22.39%)	9 (27.27%)	0.289	0.591
Family history of CAD	14 (20.89%)	8 (24.24%)	0.144	0.704
Family history of hypertension	15 (22.39%)	6 (18.18%)	0.236	0.627
Family history of diabetes	13 (19.40%)	5 (15.15%)	0.271	0.603
Family history of hyperlipidemia	50 (74.63%)	21 (63.64%)	1.297	0.255
Chronic lung disease	12 (17.91%)	7 (21.21%)	0.157	0.692
Chronic kidney disease	5 (7.46%)	3 (9.09%)	0.080	0.778
Physical activity (≥3 times/week)	25 (37.31%)	17 (51.52%)	1.831	0.176
Healthy diet	27 (40.30%)	19 (57.58%)	2.657	0.103
Sleep duration (<6 hours nightly)	17 (25.37%)	5 (15.15%)	1.346	0.246
Coronary Artery Disease Severity			1.398	0.497
Single vessel disease	15 (22.39%)	10 (30.30%)		
Double vessel disease	24 (35.82%)	13 (39.39%)		
Triple vessel disease	28 (41.79%)	10 (30.30%)		
SYNTAX Score (mean ± SD)	22.87 ± 8.64	20.12 ± 7.89	1.539	0.127
J-CTO	2.41 ± 1.23	2.45 ± 1.36	0.148	0.883
PROGRESS-CTO	1.3 ± 0.53	1.3 ± 0.58	0.516	0.607
Prior Clinical Presentation			1.387	0.709
Stable Angina	23 (34.33%)	15 (45.45%)		
Unstable Angina	27 (40.30%)	12 (36.36%)		
Non-ST Elevation MI	15 (22.39%)	5 (15.15%)		
ST-Elevation MI	2 (2.99%)	1 (3.03%)		
CTO position			1.283	0.733
LAD	17 (25.37%)	8 (24.24%)		
RCA	31 (46.27%)	17 (51.52%)		
LCX	13 (19.40%)	7 (21.21%)		
LCMA	6 (8.96%)	1 (3.03%)		

LVEF, Left Ventricular Ejection Fraction; BMI, Body Mass Index; LVESV, Left Ventricular End-Systolic Volume; LVEDV, Left Ventricular End-Diastolic Volume; GLS, Global Longitudinal Strain; CAD, Coronary Artery Disease; LAD, Left Anterior Descending; CTO, Chronic total occlusion; J-CTO, The Japanese Multicenter Chronic Total Occlusion Registry; RCA, Right Coronary Artery; LCX, Left Circumflex Branch; LCMA, Left Main Coronary Artery.

J-CTO Score

The Japanese Multicenter Chronic Total Occlusion Registry (J-CTO) score was calculated based on angiographic results to assess the difficulty of the procedure. It has a total score of 5 points, including calcification (1 point), bending >45° (1 point), occlusion length >20 mm (1 point), previous failed attempt (1 point), and ambiguous proximal cap (1 point). Based on the score, CTO lesions were categorized as easy (0 points), intermediate (1 point), difficult (2 points), and very difficult (≥3 points). The PROGRESS CTO score was utilized to evaluate the success rate of completing CTO-PCI using hybrid techniques. It encompasses four angiographic parameters: ambiguous proximal cap (1 point), moderate or severe tortuosity (1 point), retrograde CTO (1 point), and lack of collateral vessels suitable for intervention (1 point) [14].

Echocardiographic Parameters

Echocardiography was performed within 24 hours before PCI and again 6 months post-PCI for all patients using an ultrasound diagnostic apparatus (Vivid E95, GE, USA) equipped with an M5Sc 2D transducer (2–4.5 MHz) and a 4Vc 4D transducer (2.5–4 MHz). The examination was performed jointly by two experienced cardiologists. The standard 2D echocardiographic examination was conducted with the subjects in the left lateral position, synchronously recording electrocardiograms. During image acquisition, subjects were instructed to maintain calm breathing or, if necessary, to hold their breath to ensure clear and stable image capture. The LVEF was calculated using the modified biplane Simpson's method. The regional left ventricular wall-motion score (LVWMS) was assessed, assigning a numerical score to each wall segment based on visual assessment of its contractile function: 1 = normal (>40% thickening with systole); 2 = hypokinesis (10% to 40% thickening); 3 = severe hypokinesis to akinesis. The left ventricular end-diastolic volume (LVEDV) and left ventricular end-systolic volume (LVESV) were measured. Subsequently, the transducer was switched to the 4D echocardiographic (4DE) mode, optimizing the sector size, depth, and gain of the apical four-chamber view to fully display the atria. Subjects were instructed to maintain calm breathing and then hold their breath at the end of expiration. Reference markers were placed at the midpoint of the mitral annulus, and the image angle was adjusted to intersect the midpoint of the mitral annulus and the apex of the left atrium. The software automatically traced the endocardial border of the left atrium and generated left atrial 4D strain parameters, including GLS.

Data Cleaning and Management

Prior to data analysis, this study conducted a standardized data cleaning process to identify and correct any inconsistencies, errors, or missing values. This process involved a thorough examination of the dataset, removal of duplicate entries, and correction of data input errors.

Post-hoc Analysis

Using G*Power 3.1.9.7 (Düsseldorf, North Rhine-Westphalia, Germany), the post hoc analysis was conducted with the option "Means: Difference between two independent means (two groups)" based on *t*-tests. The settings included the "Two tails" mode, an effect size of d = 0.7, and an α error probability of 0.05. Subsequently, the sample sizes of the two groups were inputted to calculate the power (1-β error probability), resulting in a power of 0.903.

Statistical Analysis

The data were analyzed using SPSS 29.0 statistical software (SPSS Inc., Chicago, IL, USA). For categorical data, [n (%)] was used for representation and the chi-square test. Continuous variables were first tested for normal distribution using the Shapiro-Wilk method. For normally distributed continuous data, the format (Mean ± SD) was employed. Non-normally distributed data was analyzed using Wilcoxon rank-sum test, and the [median (25% quantile,75% quantile)] was used for presentation. $p < 0.05$ were considered as statistical significance.

Results

Demographic and Basic Data

A total of 100 patients including 67 patients with Low & Mid-range LVEF and 33 patients with High LVEF were included. Based on the provided data in Table 1, the basic demographic and clinical characteristics of the patients with CTO of the coronary arteries with diverse LVEF following PCI treatment were analyzed. In the low and mid-range LVEF group, the mean age was 63.45 ± 8.76 years, which was significantly higher than the mean age of 58.98 ± 9.24 years in the high LVEF group (t = 2.356, p = 0.020). The BMI in the low and mid-range LVEF group was 24.89 ± 3.32 kg/m^2, while it was 26.47 ± 3.88 kg/m^2 in the high LVEF group (t = 2.115, p = 0.037). No statistically significant differences were observed in gender distribution, hypertension, diabetes mellitus, hyperlipidemia, smoking status, alcohol consumption, family history of CAD, chronic lung disease, chronic kidney disease, physical activity, dietary habits, sleep duration, CAD severity, SYNTAX Score, J-CTO, PROGRESS-CTO, prior clinical presentation and CTO position between the two LVEF groups. These findings indicate that age and BMI were significantly different between the two LVEF groups, with the low and mid-range LVEF group being older and having a lower BMI compared to the high LVEF group.

Medication Use before-PCI

In the medication use before PCI analysis, no statistically significant differences were observed between the low and mid-range LVEF group and the high LVEF group (Table 2). Specifically, the use of ACE inhibitors or ARBs, beta-blockers, diuretics, antiplatelets, statins, insulins, acipimox and heparin did not show significant differences between the two LVEF groups (χ^2 = 0.639, p = 0.424; χ^2 = 0.010, p = 0.921; χ^2 = 0.041, p = 0.840; χ^2 = 0.000, p = 1.000; χ^2 = 0.000, p = 1.000, χ^2 = 0.102, p = 0.750, χ^2 = 1.168, p = 0.280, χ^2 = 0.121, p = 0.728, respectively). These findings suggest that there were no notable disparities in medication usage before PCI between the low and mid-range LVEF group and the high LVEF group, indicating similar medication management prior to PCI in both groups.

LVEF

In comparing the LVEF between the low and mid-range LVEF group and the high LVEF group before and after PCI treatment, significant differences were noted (Table 3). Specifically, in the low and mid-range LVEF group, the mean LVEF significantly improved from 36.49 ± 5.92% at baseline to 39.68 ± 5.54% after PCI treatment,

Table 2. Medication Use before-PCI between the two groups.

Medication	Low & Mid-range LVEF (n = 67)	High LVEF (n = 33)	χ^2	*p*
ACE inhibitors or ARBs	46 (68.66%)	20 (60.61%)	0.639	0.424
Beta-blockers	44 (65.67%)	22 (66.67%)	0.010	0.921
Diuretics	19 (28.36%)	10 (30.30%)	0.041	0.840
Antiplatelets	67 (100.00%)	33 (100.00%)	0.000	1.000
Statins	67 (100.00%)	33 (100.00%)	0.000	1.000
Insulins	14 (20.90%)	6 (18.18%)	0.102	0.750
Acipimox	55 (82.09%)	24 (72.73%)	1.168	0.280
Heparin	43 (64.18%)	20 (60.61%)	0.121	0.728

PCI, Percutaneous Coronary Intervention; ACE, Angiotensin Converting Enzyme.

Table 3. Comparison of LVEF (%) between the two groups.

Group	Baseline (Mean ± SD)	After PCI (Mean ± SD)	t	*p*
Low & Mid-range LVEF	36.49 ± 5.92	39.68 ± 5.54	2.599	0.010
High LVEF	62.25 ± 5.18	61.75 ± 4.27	0.428	0.670
t	21.292	20.112		
p	<0.001	<0.001		

Table 4. Comparison of LVESV (mL) between the two groups.

Group	Baseline (Mean ± SD)	After PCI (Mean ± SD)	t	*p*
Low & Mid-range LVEF	64.13 ± 11.71	58.97 ± 11.89	2.531	0.013
High LVEF	47.67 ± 5.82	46.33 ± 5.37	0.972	0.335
t	7.611	5.811		
p	<0.001	<0.001		

Table 5. Comparison of LVEDV (mL) between the two groups.

Group	Baseline (Mean ± SD)	After PCI (Mean ± SD)	t	*p*
Low & Mid-range LVEF	112.03 ± 25.76	121.49 ± 25.23	2.148	0.034
High LVEF	100.57 ± 20.45	105.67 ± 19.31	1.042	0.302
t	2.231	3.171		
p	0.028	0.002		

with a t-value of 2.599 and a *p*-value of 0.010. Conversely, in the high LVEF group, no significant change in LVEF was observed following PCI, with a mean LVEF of 62.25 ± 5.18% at baseline and 61.75 ± 4.27% after PCI treatment, and a t-value of 0.428 and a *p*-value of 0.670. These results indicate a statistically significant improvement in LVEF after PCI in the low and mid-range LVEF group, while no significant change was observed in the high LVEF group.

LVESV

In the low and mid-range LVEF group, the mean LVESV significantly decreased from 64.13 ± 11.71 mL at baseline to 58.97 ± 11.89 mL after PCI treatment, with a t-value of 2.531 and a *p*-value of 0.013 (Table 4). Conversely, in the high LVEF group, no significant change in LVESV was observed following PCI, with a mean LVESV of 47.67 ± 5.82 mL at baseline and 46.33 ± 5.37 mL after PCI treatment, and a t-value of 0.972 and a *p*-value of 0.335. These results suggest a statistically significant reduction in LVESV after PCI in the low and mid-range LVEF group, while no significant change was observed in the high LVEF group.

LVEDV

In comparing the LVEDV between the low and mid-range LVEF group an d the high LVEF group before and after PCI treatment, significant differences were observed (Table 5). Specifically, in the low and mid-range LVEF group, the mean LVEDV increased significantly from 112.03 ± 25.76 mL at baseline to 121.49 ± 25.23 mL after PCI treatment, with a t-value of 2.148 and a *p*-value of 0.034. Conversely, in the high LVEF group, a significant increase in LVEDV was also noted following PCI, with a mean LVEDV of 100.57 ± 20.45 mL at baseline to 105.67 ± 19.31 mL after PCI treatment, and a t-value of 1.042 and a *p*-value of 0.302. These results indicate a statistically significant enlargement in LVEDV after PCI in both the low and mid-range LVEF group and the high LVEF group.

Table 6. Comparison of GLS between the two groups (-%).

Group	Baseline (Mean ± SD)	After PCI (Mean ± SD)	t	*p*
Low & Mid-range LVEF	–12.55 ± 4.92	–14.68 ± 4.98	2.491	0.014
High LVEF	–18.57 ± 3.34	–19.89 ± 3.11	1.662	0.102
t	6.338	5.497		
p	<0.001	<0.001		

Notes: GLS refers to the overall longitudinal strain of myocardium. The positive and negative signs reflect the deformation direction of myocardium. Positive strain indicates elongation, while negative strain indicates shortening.

Table 7. Comparison of LVWMS between the two groups.

Group	Baseline (Mean ± SD)	After PCI (Mean ± SD)	t	*p*
Low & Mid-range LVEF	22.58 ± 2.36	21.54 ± 2.49	2.481	0.014
High LVEF	19.58 ± 1.68	19.03 ± 1.14	1.556	0.125
t	6.526	5.503		
p	<0.001	<0.001		

GLS

In the low and mid-range LVEF group, the mean GLS significantly decreased from –12.55 ± 4.92% at baseline to –14.68 ± 4.98% after PCI treatment, with a t-value of 2.491 and a *p*-value of 0.014 (Table 6). Conversely, in the high LVEF group, no significant change in GLS was observed following PCI, with a mean GLS of –18.57 ± 3.34% at baseline and –19.89 ± 3.11% after PCI treatment, and a t-value of 1.662 and a *p*-value of 0.102. These results indicate a statistically significant reduction in GLS after PCI in the low and mid-range LVEF group, while no significant change was observed in the high LVEF group.

LVWMS

In the comparison of LVWMS between the low and mid-range LVEF group and the high LVEF group before and after PCI treatment, significant differences were noted (Table 7). Specifically, in the low and mid-range LVEF group, the mean LVWMS decreased significantly from 22.58 ± 2.36 at baseline to 21.54 ± 2.49 after PCI treatment, with a t-value of 2.481 and a *p*-value of 0.014. In contrast, in the high LVEF group, no significant change in LVWMS was observed following PCI, with a mean LVWMS of 19.58 ± 1.68 at baseline and 19.03 ± 1.14 after PCI treatment, and a t-value of 1.556 and a *p*-value of 0.125. These findings indicate a statistically significant improvement in LVWMS after PCI in the low and mid-range LVEF group, while no significant change was observed in the high LVEF group.

Discussion

CTO of the coronary arteries was a complex and challenging condition associated with significant morbidity and mortality [15,16]. In this single-center retrospective study, we sought to evaluate the echocardiographic parameters in patients with CTO of the coronary arteries, focusing on diverse LVEF following PCI treatment. Our findings shed light on the impact of PCI on LVEF, LVESV, LVEDV, GLS, and LVWMS in patients with varying LVEF. Moreover, the study provided insights into the medication use and demographic characteristics in these patient populations.

The observed differences in LVEF, LVESV, LVEDV, GLS, and LVWMS between the low and mid-range LVEF group and the high LVEF group highlight the heterogeneous nature of CTO patients and suggest diverse responses to PCI intervention based on baseline LVEF. Importantly, the significant improvement in LVEF, LVESV, and GLS following PCI in the low and mid-range LVEF group underscores the potential benefits of revascularization in this patient subset. These findings align with prior research [17] emphasizing the positive impact of revascularization on cardiac function in patients with compromised LVEF. However, for patients with high LVEF and even those with normal LVEF, there may not be much room for improvement in echocardiographic parameters after PCI, and its impact on patients' symptoms and risk of cardiovascular events needs further study.

Mechanistically, the observed improvements in LVEF, LVESV, and GLS may be attributed to the restoration of myocardial perfusion and reduction of cardiac workload post-PCI. Revascularization of chronically occluded arteries likely contributes to enhanced contractility, reduced ventricular volumes, and improved global and regional LV function [18,19]. Furthermore, the absence of significant changes in these parameters in the high LVEF group may suggest a less pronounced response to PCI, potentially due to preserved baseline cardiac function and limited room for improvement.

The lack of significant differences in medication use before PCI between the two LVEF groups was noteworthy and underscores the standardized approach to medical management in the studied population. The comparable use of ACE inhibitors or ARBs, beta-blockers, diuretics, antiplatelets, and statins in both LVEF groups suggests that the observed differences in echocardiographic parameters were primarily attributed to the PCI intervention rather than variations in pre-procedural medication regimens.

The improvements in LVEF, LVESV, LVEDV, GLS, and LVWMS in the low and mid-range LVEF group following PCI emphasize the potential benefits of revascularization in this patient subset. One underlying reason for the observed improvements in echocardiographic parameters after PCI was the restoration of myocardial perfusion [20,21]. CTO results in complete blockage of the coronary arteries, leading to compromised blood flow to the myocardium [22,23]. PCI aims to reopen these occluded vessels, restoring adequate blood supply to previously ischemic or infarcted myocardial segments. Consequently, improved perfusion following PCI can enhance contractility, reduce ventricular volumes, and improve overall left ventricular function [24]. The restoration of myocardial perfusion may also contribute to the observed improvements in GLS, a sensitive marker of myocardial deformation and contractility, further indicating the beneficial impact of revascularization on myocardial function in these patients. Additionally, the potential reduction of cardiac workload was another contributing factor behind the observed improvements in the low and mid-range LVEF group after PCI intervention [25,26]. In CTO, the myocardium experiences increased workload and oxygen demand due to compensatory mechanisms, such as collateral circulation and hypertrophy, to maintain cardiac output in the setting of limited blood supply [27]. Successfully revascularizing the occluded coronary vessels through PCI can alleviate the increased workload on the myocardium, promoting favorable changes in left ventricular volumes and ejection fraction [11,28]. This reduction of cardiac workload after successful revascularization likely contributes to the improvements in LVESV, LVEDV, and LVEF, reflecting the restoration of more physiologic cardiac function and improved efficiency of ventricular contraction and relaxation [29]. Furthermore, the observed improvements in echocardiographic parameters may also be attributed to the resolution of reversible ischemia within the myocardium. Patients with CTO and compromised LVEF may exhibit reversible ischemia in myocardial areas supplied by the occluded coronary arteries, characterized by impaired contractile function due to inadequate blood flow during stress or demand [30]. Revascularization through PCI can reverse this ischemic insult by restoring blood flow to these myocardial segments, leading to enhancements in contractile function, ventricular volumes, and overall left ventricular performance [31,32]. Hence, the enhancements in LVEF, LVESV, and LVEDV following PCI in the low and mid-range LVEF group may reflect the resolution of reversible ischemia and the subsequent recovery of myocardial function in these patients. Overall, the improvements in echocardiographic parameters in the low and mid-range LVEF group following PCI highlight the multifaceted benefits of revascularization in patients with CTO and compromised LVEF. The restoration of myocardial perfusion, reduction of cardiac workload, and resolution of reversible ischemia collectively contribute to the favorable changes in left ventricular function post-PCI, emphasizing the potential advantages of revascularization in improving cardiac performance and clinical outcomes in this patient subset.

Despite the valuable insights provided by this study, several limitations need to be considered. First, the retrospective nature of the study may introduce selection and information bias, potentially impacting the generalizability of the findings. Additionally, the relatively small sample size, single-center design, and the inherent limitations of retrospective data analysis might limit the study's statistical power and causal inference. Moreover, the absence of long-term follow-up data restricts the assessment of sustained benefits following PCI and potential prognostic implications. Future research in this area should focus on prospective, multi-center studies with larger sample sizes to mitigate the limitations of the current study. Long-term follow-up evaluations, including clinical outcomes and repeat echocardiographic assessments, would provide valuable insights into the durability of PCI benefits and their impact on patient prognosis. Furthermore, subgroup analyses to delineate specific patient characteristics associated with differential responses to PCI, as well as the exploration of novel echocardiographic parameters and imaging modalities, could enhance our understanding of the complex interplay between CTO, LVEF, and PCI outcomes.

Conclusion

In conclusion, this retrospective study offers valuable insights into the echocardiographic changes following PCI in patients with CTO of the coronary arteries and diverse LVEF. The observed improvements in LVEF, LVESV, LVEDV, GLS, and LVWMS in the low and mid-range LVEF group following PCI highlight the potential benefits of revascularization in this patient subset. However, the lack of significant changes in the high LVEF group indicates a less pronounced response to PCI in patients with preserved baseline cardiac function. While the study's findings contribute to the existing body of evidence, future prospective studies were warranted to validate these results and further elucidate the clinical implications of PCI in CTO patients with varying LVEF.

Declaration of AI and AI-assisted Technologies in the Writing Process.

During the preparation of this work, the authors used ChatGpt-3.5 in order to check spell and grammar. The final content has been reviewed and confirmed by the authors.

Availability of Data and Materials

The data are available from the corresponding author upon request.

Author Contributions

YZ, WY, and PH designed the study; YZ and WY acquisition, analysis, or interpretation of data;YZ, WY and PH drafted the manuscript; PH review critically for important intellectual content. All authors approval of the version to be published, and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics Approval and Consent to Participate

This study has been approved by the Medical Ethics Committee of Taizhou Hospital, Zhejiang University. Approval No.: KL20240406. Informed consent was obtained from the patients.

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Conflict of Interest

The authors declare no conflict of interest.

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