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ORIGINAL RESEARCH

Health Status Outcomes in Older Adults Undergoing Chronic Total Occlusion Percutaneous Coronary Intervention

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BACKGROUND: Although chronic total occlusions (CTOs) are common in older adults, they are less likely to be offered CTO percutaneous coronary intervention for angina relief than younger adults. The health status impact of CTO percutaneous coronary intervention in adults aged ≥75 years has not been studied. We sought to compare technical success rates and angina-related health status outcomes at 12 months between adults aged ≥75 and <75 years in the OPEN-CTO (Outcomes, Patient Health Status, and Efficiency in Chronic Total Occlusion) registry.

METHODS AND RESULTS: Angina-related health status was assessed with the Seattle Angina Questionnaire (score range 0–100, higher scores denote less angina). Technical success rates were compared using hierarchical modified Poisson regression, and 12-month health status was compared using hierarchical multivariable linear regression between adults aged ≥75 and <75 years. Among 1000 participants, 19.8% were ≥75 years with a mean age of 79.5±4.1 years. Age ≥75 years was associated with a lower likelihood of technical success (adjusted risk ratio=0.92 [95% CI, 0.86–0.99; *P*=0.02]) and numerically higher rates of in-hospital major adverse cardiovascular events (9.1% versus 5.9%, *P*=0.10). There was no difference in Seattle Angina Questionnaire Summary Score at 12 months between adults aged ≥75 and <75 years (adjusted difference=0.9 [95% CI, −1.4 to 3.1; *P*=0.44]).

CONCLUSIONS: Despite modestly lower success rates and higher complication rates, adults aged ≥75 years experienced angina-related health status benefits after CTO-percutaneous coronary intervention that were similar in magnitude to adults aged <75 years. CTO percutaneous coronary intervention should not be withheld based on age alone in otherwise appropriate candidates.

Key Words: chronic total occlusion ■ health status ■ older adults ■ percutaneous coronary intervention

Chronic total occlusions (CTOs) are common in older adults with coronary artery disease, with prior studies reporting a prevalence of nearly 4 in 10 patients aged >65 years.[1] Given an aging US population,[2] better understanding the management of patients with these complex lesions is of critical importance. Older age remains one of the most significant risk factors for adverse events after percutaneous coronary intervention (PCI),[3–5] and older patients are more likely to have multiple comorbidities, coronary calcification, and frailty which also increases the risk of poor outcomes.[6–8] Contemporary studies of clinical outcomes in adults aged ≥75 years undergoing CTO PCI have demonstrated lower technical success and higher in-hospital major adverse cardiovascular events (MACE) as compared with adults aged <75 years[9]; however, there are limited data on health

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CLINICAL PERSPECTIVE

What Is New?

- Chronic total occlusions (CTOs) are common in older adults with coronary artery disease, which may cause significant impairments to health status and quality of life; however, older adults are less likely to be referred for CTO percutaneous coronary intervention (PCI) than younger adults, as increasing age is associated with more complex coronary disease and a greater risk of periprocedural complications.
- In a registry of participants undergoing CTO PCI at experienced centers, technical success rates were modestly lower and in-hospital complication rates were higher in adults aged ≥75 years compared with <75 years.
- Despite lower success rates and higher complication rates, adults aged ≥75 years experienced large, rapid, and sustained improvements in health status up to 1-year after CTO PCI that were similar in magnitude to adults aged <75 years.

What Are the Clinical Implications?

- Our study highlights the utility of CTO-PCI performed at experienced centers in improving symptoms, physical functioning, and quality of life in older adults.
- This information can be used to improve shared decision-making and counsel older adults with CTOs on the risks and health status benefits of CTO PCI.
- At experienced centers, advanced age should not be considered a barrier to offering CTO PCI to otherwise appropriate candidates.

Nonstandard Abbreviations and Acronyms

CTO	chronic total occlusion
RDS	Rose Dyspnea Scale
SAQ	Seattle Angina Questionnaire

status outcomes after treatment—patients' symptoms, physical function, and quality of life (QOL). The EURO-CTO trial (Randomized Multicentre Trial to Evaluate the Utilization of Revascularization or Optimal Medical Therapy for the Treatment of Chronic Total Coronary Occlusions), the only randomized study to find a health status benefit with CTO PCI, randomized 396 participants (mean age 65.2 years) 2:1 to CTO PCI versus medical therapy, but only roughly 16% of participants were ≥75 years, limiting generalizability to older adults.[10] In light of increased procedural risks and uncertain health status benefits among older patients, it is critical to understand if older adults derive comparable symptom relief as younger adults as they may be less likely to undergo CTO PCI than younger adults in routine practice.[11]

For older adults, QOL and functional independence may be a much more significant priority than longevity when considering treatment options.[12,13] The decision to undergo CTO PCI may be particularly compelling for many older patients if symptoms, physical functioning, and QOL are likely to significantly improve; however, the impact of CTO PCI on these important patient-centered outcomes has not been studied among older adults. To address this knowledge gap, we leveraged the OPEN-CTO (Outcomes, Patient Health Status, and Efficiency in Chronic Total Occlusion Hybrid Procedures) registry to quantify health status outcomes after CTO PCI using the Seattle Angina Questionnaire (SAQ) and Rose Dyspnea Scale (RDS). We also compared rates of technical success and procedural complications in older versus younger participants undergoing CTO PCI. Quantifying older patients' health status outcomes after CTO-PCI will provide essential insights to help clinicians better convey the expected risks and benefits of treatment and improve the shared decision-making process in this increasingly important population.

METHODS

Data Source and Study Population

Anonymized data that support the findings of this study can be made available from the corresponding author upon reasonable request. The OPEN-CTO study is a prospective, multicenter, single-arm registry that enrolled 1000 patients undergoing CTO PCI from 12 US sites between January 21, 2014 to July 22, 2015. The study rationale and design has been previously published.[14] Briefly, all participants scheduled to receive CTO PCI were consecutively screened for inclusion to avoid selection bias, a key limitation of previous CTO registries. Each participant enrolled in OPEN-CTO was linked to the NCDR (National Cardiovascular Disease Registry) Cath/PCI registry, which allowed for auditing the success of consecutive enrollment.[14] All participants were treated by highly experienced operators using the previously published hybrid algorithm for CTO PCI.[15] Each operator was required to have a minimum of 2 years of experience performing CTO PCI and to have performed at least 100 procedures before participating in the registry. The study was approved by each institution's institutional review board, and all participants provided written informed consent.

Participants were included in the study if they were aged ≥18 years and had a CTO, defined as a 100% occlusion with antegrade intraluminal Thrombolysis in Myocardial Infarction grade 0 flow, with clinical or angiographic evidence of duration >3 months. Key exclusion criteria included the presence of a CTO in a bypass graft, patients who were non-English speaking, hard of hearing, had dementia, or were too ill to interview via telephone. Baseline sociodemographic, clinical, and health status data were collected by trained research coordinators. Follow-up health status and rehospitalization assessments were conducted at 1, 6, and 12 months by telephonic interview by trained staff at the coordinating call center.

Outcomes and Definitions

The primary outcome was angina-related health status at 12-months post-CTO PCI measured with the 19-item Seattle Angina Questionnaire (SAQ).[16] The SAQ captures the frequency of angina (SAQ Angina Frequency), the effect of angina on physical functioning (SAQ Physical Limitations), and angina-related QOL (SAQ Quality of Life) scores over the prior 4 weeks, and has been shown to be highly valid, reliable, and sensitive to change in clinical status.[16–18] Scores range from 0 to 100, with higher scores signifying less angina, better physical functioning, and higher QOL. Scores for each domain are averaged to create an SAQ Summary Score. To facilitate interpretability, scores for each domain can be categorized into scores of 0 to 24 (very poor to poor health status), 25 to 49 (poor to fair), 50 to 75 (fair to good), and 76 to 100 (good to excellent). For SAQ Angina Frequency, score ranges of 0 to 30, 31 to 60, 61 to 99, and 100 represent daily, weekly, monthly, and no angina, respectively.[19] SAQ scores have been found to be predictive of future death, acute coronary syndrome, and increasing health care costs,[20,21] and a 5-point difference in scores is considered a clinically important difference.[22]

Because older patients may be more likely to present with dyspnea as an anginal equivalent, severity of dyspnea was assessed with the Rose Dyspnea Scale (RDS). The RDS assesses whether dyspnea is present with 4 common physical activities and 1 point is assigned to each activity where dyspnea occurs, with scores of 0 indicating no dyspnea and scores of 4 indicating significant limitations because of dyspnea.[23] A change in RDS of 1 represents a clinically important difference.

Technical success was defined as <50% residual stenosis and Thrombolysis in Myocardial Infarction grade ≥2 flow without significant side branch occlusions,[24] as assessed by a central angiographic core laboratory (Saint Luke's Mid America Heart Institute, Kansas City, Missouri). Complete revascularization was defined by the operator as successful treatment of all physiologically significant coronary stenoses. Perforations were categorized using the Ellis classification system by angiographic core laboratory review.[25] A significant perforation was defined as any perforation that required treatment.

Major adverse cardiovascular and cerebrovascular events (MACCE) were defined as the composite of death, periprocedural myocardial infarction, emergency coronary bypass surgery, stroke, and clinically significant perforation. Periprocedural myocardial infarction was defined according to the European Society of Cardiology/American College of Cardiology/American Heart Association/World Health Federation task force Universal Definition of Myocardial Infarction subtypes 4a and 5.[26] The cumulative incidence of all-cause hospital readmission was assessed at 1, 6, and 12 months after CTO PCI. All procedural angiograms were reviewed using QAngio XA 7.3 software (Medis Medical Imaging Systems, Leiden, The Netherlands).

Statistical Analysis

For the primary analysis, we categorized patients as aged ≥75 and <75 years. This threshold was chosen based on the known knowledge gaps in health status outcomes in adults ≥75 years, the underrepresentation of adults ≥75 years from prior CTO revascularization studies,[10,27] and studies demonstrating comparatively fewer adults aged 70 to 79 and ≥80 years being referred for CTO PCI.[11] Continuous variables were summarized as means±SDs or medians (interquartile range), and categorical variables as counts (percentage). For descriptive purposes, continuous variables were compared between the 2 groups with the 2-tailed t test or Wilcoxon Rank Sum test, and categorical variables were compared with χ^2 analysis. As a supplementary analysis, we also compared differences in baseline characteristics, procedural characteristics, and health status outcomes among adults aged <65, 65 to 74, and ≥75 years using 1-way ANOVA or the Kruskal–Wallis test for continuous variables and χ^2 analysis for categorical variables.

We examined the association between age category (aged ≥75 and <75 years) and technical success using hierarchical modified Poisson regression with robust error variance to account for clustering of patients within sites.[28] Covariates for model adjustment were determined a priori based on clinical experience, and included vessel treated, presence of a bypass graft to the CTO vessel, prior stenting of the CTO vessel, and each component of the Japan CTO score: presence of a blunt proximal cap, vessel calcification, vessel bending ≥45°, CTO length ≥20 mm, and whether the current procedure was a repeat attempt of a previously failed CTO PCI.

For the health status outcomes analysis, we excluded 37 of the 1000 patients enrolled in OPEN-CTO with missing baseline health status or all 3 follow-up health status assessments. Unadjusted health status outcomes were compared between adults ≥75 and <75 years at baseline, 1, 6, and 12-months. Differences in health status between adults aged ≥75 years and adults <75 years were modeled using hierarchical multivariable linear regression with repeated measures, which allowed for better informing of the 12-month estimate (the primary health status outcome of interest) using 1 and 6-month estimates. Models were developed for SAQ Summary Score, SAQ Angina Frequency Score, SAQ Physical Limitations, SAQ QOL, and RDS. Each model included age and time as categorical effects, an age by time interaction, and adjusted for the corresponding baseline health status as a restricted cubic spline term. Each model was further adjusted for potential confounders based on clinical experience, including sex, diabetes, congestive heart failure, chronic lung disease, prior myocardial infarction, chronic kidney disease, and whether technical success was achieved. We also included a sex-by-age interaction, as sex-related differences in cardiovascular risk profiles may lead to differential health status benefits in older women as compared with older men.[29] In a sensitivity analysis, we repeated the above analysis adjusting for in-hospital MACCE.

A *P* value of <0.05 was considered statistically significant. All statistical analyses were performed in SAS version 9.4 (SAS Institute, Cary, NC USA).

RESULTS

Of the 1000 patients consecutively enrolled in the OPEN-CTO study, 198 (19.8%) adults were ≥75 years with a mean age of 79.5±4.1 years (Table 1). The mean age of adults <75 years was 61.9±8.1 years. Compared with adults aged <75 years, adults ≥75 years were more likely to be women and have a history of previous coronary artery bypass grafting, chronic kidney disease, atrial fibrillation, and peripheral artery disease. Adults ≥75 years were less likely to be smokers and had lower body mass indexes than adults <75 years. Rates of previous myocardial infarction, PCI, and congestive heart failure were similar between age groups. There were no differences in clinical presentation between older and younger adults, with most participants being referred to CTO PCI for stable angina. Characteristics of adults aged <65, 65 to 74, and ≥75 years are presented in Tables S1–S6.

There were no differences in mean Japan CTO score (2.4±1.3 versus 2.3±1.2, *P*=0.35), mean lesion length (60.2±30.2 versus 61.2±28.0 mm, *P*=0.65), vessel treated, or first crossing strategy between adults aged ≥75 and <75 years (Table 2). Adults ≥75 years were more likely to have vessel calcification (40.4% versus 30.5%, *P*=0.008) and a prior bypass to the target vessel (39.9% versus 27.6%, *P*<0.001) compared with adults <75 years, but rates of vessel tortuosity and reattempt CTO PCI were similar between age groups. Crude rates of technical success were lower in adults ≥75 years as compared with <75 years (80.3% versus 87.8%, *P*=0.006). After adjusting for potential anatomic confounders, age ≥75 years was associated with 8% lower rates of technical success (risk ratio=0.92 [95% CI, 0.86–0.99; *P*=0.02]). Additional predictors of technical success included whether CTO PCI was being reattempted (*P*=0.002) and whether there was prior bypass grafting of CTO vessel (*P*<0.001).

Coronary perforation was the most common intraprocedural complication in both groups. There was a numerically higher rate of coronary perforation (12.1% versus 8.0%, *P*=0.07) and in-hospital MACCE (9.1% versus 5.9%, *P*=0.10) in adults ≥75 years compared with adults <75 years, although rates of pericardial effusion development were similar. Other complications such as in-hospital death, periprocedural myocardial infarction, stroke, contrast nephropathy, and access site bleeding were not significantly different between age groups. There was no difference in the cumulative incidence of all-cause hospital readmission at 1, 6, and 12 months between age groups. Similar trends in technical success rates and procedural complications were observed when patient ages were categorized by <65, 65 to 74, and ≥75 years (Table S2).

Health Status Outcomes

Of the 1000 patients enrolled in OPEN-CTO, 37 were missing a baseline SAQ or all 3 follow-up SAQ assessments and were excluded, yielding a total of 963 patients for the health status analysis. There were minimal differences in comorbidity burden and no differences in baseline health status between included and excluded patients, although excluded patients were more likely to have procedural complications and in-hospital MACCE (Tables S3 and S4).

Baseline health status by age category is presented in Table 3. Compared with adults aged <75 years, those ≥75 years had similar SAQ Summary (63.8±22.6 versus 61.1±22.5, *P*=0.14), Angina Frequency (71.5±28.2 versus 70.0±26.8, *P*=0.48), and Physical Limitation scores (62.4±26.5 versus 65.9±26.1, *P*=0.11), although QOL scores were higher in older adults (56.5±26.5 versus 47.5±27.3, *P*<0.001). There were no differences in the proportion of adults aged ≥75 and <75 years experiencing any angina (ie, SAQ Angina Frequency Score<100) (68.4% versus 72.1%, *P*=0.32). Baseline RDS values were similar between adults aged ≥75 and <75 years (2.3±1.5 versus 2.2±1.5, *P*=0.67). Among those without angina but who had dyspnea (SAQ Angina Frequency=100,

Table 1. Baseline Characteristics of Patients Aged ≥75 and <75 years

	Age ≥75 y	Age <75 y	Total	
	n=198	n=802	n=1000	*P* value
Demographics				
Age, y	79.5±4.1	61.9±8.1	65.4±10.3	<0.001
Sex				<0.001
Men	141 (71.2%)	663 (82.7%)	804 (80.4%)	
Women	57 (28.8%)	139 (17.3%)	196 (19.6%)	
Race				0.50
White	183 (92.4%)	719 (89.7%)	902 (90.2%)	
Black	6 (3.0%)	33 (4.1%)	39 (3.9%)	
Other	9 (4.5%)	50 (6.2%)	59 (5.9%)	
Comorbidities				
BMI	28.1±5.0	31.0±6.1	30.5±6.0	<0.001
Current smoker	8 (4.1%)	125 (15.7%)	133 (13.4%)	<0.001
History of diabetes	80 (40.4%)	332 (41.4%)	412 (41.2%)	0.80
History of CHF	55 (27.8%)	174 (21.7%)	229 (22.9%)	0.07
History PAD	44 (22.2%)	131 (16.3%)	175 (17.5%)	0.05
History of MI	90 (45.5%)	394 (49.1%)	484 (48.4%)	0.35
History of hypertension	172 (86.9%)	686 (85.5%)	858 (85.8%)	0.63
History CKD	38 (19.2%)	97 (12.1%)	135 (13.5%)	0.008
History of atrial fibrillation	60 (30.3%)	93 (11.6%)	153 (15.3%)	<0.001
History of lung disease	33 (16.7%)	111 (13.8%)	144 (14.4%)	0.31
Prior PCI	127 (64.1%)	529 (66.0%)	656 (65.7%)	0.61
History of CABG	95 (48.0%)	270 (33.7%)	365 (36.5%)	<0.001
History of stroke	7 (3.5%)	21 (2.6%)	28 (2.8%)	0.48
Type of angina				0.60
Stable	161 (91.0%)	671 (92.2%)	832 (91.9%)	
Unstable	16 (9.0%)	57 (7.8%)	73 (8.1%)	
LV systolic function				0.43
None	116 (61.4%)	475 (65.6%)	591 (64.7%)	
Mild	38 (20.1%)	110 (15.2%)	148 (16.2%)	
Moderate	19 (10.1%)	72 (9.9%)	91 (10.0%)	
Severe	16 (8.5%)	67 (9.3%)	83 (9.1%)	
Laboratory results				
eGFR (median, IQR)	65.0 (54.0, 77.4)	79.8 (63.9, 94.2)	76.8 (60.9, 92.3)	<0.001
Hemoglobin	13.0±1.7	13.7±1.6	13.6±1.7	<0.001
Last HbA1c	6.7±1.2	7.1±1.8	7.0±1.7	0.18
Medications				
Beta blocker, baseline	169 (85.4%)	679 (84.7%)	848 (84.8%)	0.81
Beta blocker, 12-mo*	139 (81.3%)	554 (78.7%)	693 (79.2%)	0.45
CCB, baseline	56 (28.3%)	182 (22.7%)	238 (23.8%)	0.01
CCB, 12-mo*	41 (24.0%)	140 (19.9%)	181 (20.7%)	0.44
Ranolazine, baseline	30 (15.2%)	117 (14.6%)	147 (14.7%)	0.84
Ranolazine, 12-mo*	14 (8.2%)	66 (9.4%)	80 (9.1%)	0.63
Long-acting nitrate, baseline	99 (50.0%)	314 (39.2%)	413 (41.3%)	0.005
Long-acting nitrate, 12-mo*	45 (26.3%)	180 (25.6%)	225 (25.7%)	0.84
Aspirin, discharge	177 (89.4%)	765 (95.4%)	942 (94.2%)	0.001
P2Y12 inhibitor, discharge	175 (88.4%)	754 (94.0%)	929 (92.9%)	0.005
Warfarin, discharge	18 (9.1%)	39 (4.9%)	57 (5.7%)	0.021
NOAC, discharge	13 (6.6%)	19 (2.4%)	32 (3.2%)	0.002

BMI indicates body mass index; CABG, coronary artery bypass grafting; CCB, calcium channel blocker; CHF, congestive heart failure; CKD, chronic kidney disease; eGFR, estimated glomerular filtration rate; LV, left ventricle; MI, myocardial infarction; NOAC, novel oral anticoagulant; PAD, peripheral artery disease; and PCI, percutaneous coronary intervention.

*Within both age groups, rates of antianginal drug use at 12 months were significantly lower as compared with baseline. All *P*<0.001 for beta-blocker, calcium channel blocker, ranolazine, and long-acting nitrate.

Table 2. Procedural Characteristics and Complications by Age Category

	Age ≥75y	Age <75y	Total	
	n=198	n=802	n=1000	*P* value
Primary CTO vessel				0.84
LM	1 (0.5%)	7 (0.9%)	8 (0.8%)	
LCx/OM	37 (18.7%)	132 (16.5%)	169 (16.9%)	
RCA/PDA/RPLV	116 (58.6%)	499 (62.2%)	615 (61.5%)	
LAD	43 (21.7%)	157 (19.6%)	200 (20.0%)	
Diagonal	1 (0.5%)	7 (0.9%)	8 (0.8%)	
J-CTO score				0.39
0	17 (8.6%)	64 (8.0%)	81 (8.1%)	
1	39 (19.7%)	151 (18.8%)	190 (19.0%)	
2	42 (21.2%)	220 (27.4%)	262 (26.2%)	
3	56 (28.3%)	230 (28.7%)	286 (28.6%)	
4	36 (18.2%)	117 (14.6%)	153 (15.3%)	
5	8 (4.0%)	20 (2.5%)	28 (2.8%)	
Mean J-CTO Score	2.4±1.3	2.3±1.2	2.3±1.2	0.35
Blunt proximal cap	130 (65.7%)	506 (63.1%)	636 (63.6%)	0.50
Calcification	80 (40.4%)	245 (30.5%)	325 (32.5%)	0.008
Bending ≥45°	112 (56.6%)	431 (53.7%)	543 (54.3%)	0.47
Lesion length ≥20 mm	121 (61.1%)	495 (61.7%)	616 (61.6%)	0.87
Previously attempted lesion	32 (16.2%)	172 (21.4%)	204 (20.4%)	0.10
Vessel tortuosity	91 (46.0%)	358 (44.6%)	449 (44.9%)	0.74
Lesion length	60.2±30.2	61.2±28.0	61.0±28.5	0.65
Prior bypass to target CTO vessel	79 (39.9%)	221 (27.6%)	300 (30.0%)	<0.001
Initial crossing strategy				0.58
Antegrade wire escalation	106 (53.5%)	441 (55.0%)	547 (54.7%)	
Antegrade dissection and re-entry	23 (11.6%)	116 (14.5%)	139 (13.9%)	
Retrograde wire escalation	30 (15.2%)	103 (12.8%)	133 (13.3%)	
Retrograde dissection and re-entry	39 (19.7%)	142 (17.7%)	181 (18.1%)	
Successful crossing strategy				0.54
Antegrade wire escalation	74 (42.0%)	301 (40.5%)	375 (40.8%)	
Antegrade dissection and re-entry	47 (26.7%)	176 (23.7%)	223 (24.3%)	
Retrograde wire escalation	19 (10.8%)	76 (10.2%)	95 (10.3%)	
Retrograde dissection and re-entry	36 (20.5%)	190 (25.6%)	226 (24.6%)	
Technical success	159 (80.3%)	704 (87.8%)	863 (86.3%)	0.006
Any non-CTO PCI	27 (13.6%)	110 (13.7%)	137 (13.7%)	0.98
Complete revascularization	148 (75.5%)	608 (76.0%)	756 (75.9%)	0.89
Total contrast used	250.5±131.9	264.8±141.3	262.0±139.5	0.20
Total radiation air kerma used	2360.1±1733.2	2577.0±1918.3	2534.0±1884.2	0.15
Total procedure time	122.4±62.0	120.3±65.0	120.7±64.4	0.67
Periprocedural complications				
Perforation	24 (12.1%)	64 (8.0%)	88 (8.8%)	0.07
Septal hematoma	3 (1.5%)	11 (1.4%)	14 (1.4%)	0.75
Pericardial effusion	6 (3.0%)	20 (2.5%)	26 (2.6%)	0.67
Hemodynamically significant	4 (66.7%)	9 (45.0%)	13 (50.0%)	0.64

(*Continued*)

Table 2. Continued

	Age ≥75y	Age <75y	Total	
	n=198	n=802	n=1000	*P* value
Access site hematoma	12 (6.1%)	31 (3.9%)	43 (4.3%)	0.17
Radiation dermatitis	1 (0.5%)	0 (0.0%)	1 (0.1%)	0.20
Contrast nephropathy	2 (1.0%)	6 (0.7%)	8 (0.8%)	0.66
Retroperitoneal bleed	0 (0.0%)	2 (0.2%)	2 (0.2%)	1.000
MACCE	18 (9.1%)	47 (5.9%)	65 (6.5%)	0.10
Death during procedure	3 (1.5%)	2 (0.2%)	5 (0.5%)	0.06
Death during hospitalization	3 (1.5%)	6 (0.7%)	9 (0.9%)	0.39
Post-procedure MI	4 (2.0%)	22 (2.7%)	26 (2.6%)	0.57
Emergency surgery	2 (1.0%)	4 (0.5%)	6 (0.6%)	0.34
Stroke	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Cumulative incidence of all-cause hospital readmission				
1-mo	18 (9.1%)	61 (7.6%)	79 (7.9%)	0.30
6-mo	59 (29.8%)	208 (25.9%)	267 (26.7%)	0.29
12-mo	81 (40.9%)	280 (34.9%)	361 (36.1%)	0.13

Vessel tortuosity defined as ≥1 bends ≥90° or ≥3 bends 45° to 90°. CTO indicates chronic total occlusion; J-CTO, Japan chronic total occlusion; LAD, left anterior descending coronary artery; LCX, left circumflex coronary artery; LM, left main coronary artery; MACCE, major adverse cardiovascular and cerebral event; MI, myocardial infarction; OM, obtuse marginal coronary artery; PDA, posterior descending coronary artery; RCA, right coronary artery; and RPLV, right posterolateral ventricular coronary artery.

RDS ≥1), 42/60 (70%) were aged ≥75 years and 136/213 (63.8%) were <75 years (*P*=0.38).

After CTO-PCI, there was a rapid and sustained mean improvement of at least 20 points in all domains of the SAQ by 1 month in both age groups (Figure 1). There were no differences in SAQ Summary Score, SAQ Angina Frequency, or proportion of patients without any angina (SAQ Angina Frequency=100) at 1, 6, or 12 months between adults aged ≥75 and <75 years. Adults ≥75 years had lower SAQ Physical Limitations scores but greater QOL scores than adults aged <75 years at each follow-up assessment. At 12 months, adults aged ≥75 years had greater RDS scores than adults <75 years (1.5±1.5 versus 1.1±1.4, *P*=0.001). Similar trends in 12-month health status outcomes were observed between adults aged <65, 65 to 74, and ≥75 years (Table S5).

After multivariable adjustment, health status at 12 months between adults ≥75 years and adults <75 years was similar, with a mean difference of 0.9 points (95% CI, −1.4 to 3.1; *P*=0.44) for SAQ Summary Score, 0.5 points (95% CI, −2.2 to 3.1; *P*=0.73) for SAQ Angina Frequency, −2.2 points (95% CI, −4.7 to 0.3; *P*=0.08) for SAQ Physical Limitations, and 3.1 (95% CI, −0.1 to 6.4; *P*=0.06) for SAQ QOL (Figure 2). The adjusted difference in RDS was 0.2 points (95% CI, 0.0 to 0.4; *P*=0.04), indicating more dyspnea after CTO PCI in adults aged ≥75 years compared with <75 years. All age-by-sex interaction *P* values were >0.10. In the sensitivity analysis, similar results were obtained when MACCE was included in the health status models (Table S6).

DISCUSSION

Although the primary goal of CTO PCI is to reduce symptom burden and improve physical functioning and QOL, the angina-related health status benefits of CTO PCI in older adults aged ≥75 years have not been previously studied. This multicenter study of unselected adults referred for CTO PCI by experienced hybrid operators directly addresses this critical gap in knowledge. Despite a greater burden of comorbidities, patients aged ≥75 years experienced rapid, substantial, and sustained angina-related health status benefits at 12 months. Importantly, after adjusting for potential confounders, there were no clinically significant differences in health status between adults aged ≥75 and <75 years after CTO PCI. Adults aged ≥75 years had slightly lower rates of technical success than adults aged <75 years on adjusted analyses, with a trend towards higher rates of periprocedural complications including perforation and MACCE. Collectively, our study adds important new insights into the treatment benefits of CTO PCI in older adults and highlights the feasibility and utility of CTO PCI in improving angina-related QOL across the spectrum of age. These data may assist clinicians in conveying the potential benefits of CTO PCI when considering treatment strategies and discussing goals of care with older patients.

Data from prior observational studies examining CTO PCI treatment outcomes in adults ≥75 years suggest lower technical success rates, higher in-hospital MACE, and greater long-term MACE compared with

Table 3. Unadjusted Baseline and Follow-Up Health Status by Age Category

	Age ≥75 y n=190	Age <75 y n=773	*P* value
SAQ Summary Score			
Baseline	63.8±22.6	61.1±22.5	0.14
1-mo	86.0±15.7	85.5±16.4	0.68
6-mo	88.5±14.4	87.9±16.3	0.66
12-mo	88.5±14.8	87.8±15.5	0.57
SAQ Angina Frequency			
Baseline	71.5±28.2	70.0±26.8	0.48
1-mo	92.6±16.9	90.5±19.2	0.17
6-mo	91.6±18.2	92.3±17.8	0.66
12-mo	93.2±18.2	93.1±17.0	0.95
Any angina			
Baseline	130 (68.4%)	557 (72.1%)	0.32
1-mo	42 (22.2%)	197 (26.1%)	0.28
6-mo	42 (23.3%)	155 (21.5%)	0.59
12-mo	31 (17.7%)	143 (19.9%)	0.50
SAQ Physical Limitations			
Baseline	62.4±26.5	65.9±26.1	0.11
1-mo	91.5±17.8	96.5±11.4	<0.001
6-mo	90.3±17.5	94.3±14.2	0.004
12-mo	91.6±18.1	95.6±12.1	0.002
SAQ Quality of Life			
Baseline	56.5±26.3	47.5±27.3	<0.001
1-mo	78.5±21.9	74.2±22.0	0.02
6-mo	83.7±18.1	79.3±22.1	0.01
12-mo	82.6±18.4	78.0±22.5	0.01
Rose Dyspnea Scale			
Baseline RDS	2.3±1.5	2.2±1.5	0.67
1-mo	1.3±1.5	1.1±1.4	0.03
6-mo	1.3±1.4	1.1±1.4	0.09
12-mo	1.5±1.5	1.1±1.4	0.001

RDS indicates Rose Dyspnea Scale; and SAQ, Seattle Angina Questionnaire.

adults aged <75 years.[9] In the largest of these studies, the US-based PROGRESS CTO registry (Prospective Global Registry for the Study of Chronic Total Occlusion Intervention), Karastakis et al. reported that age ≥75 years more than doubled the odds of technical failure and in-hospital MACE.[30] Hoebers et al. and Toma et al. similarly found lower success rates in adults aged ≥75 years, but found that successful CTO PCI to be associated with reductions in long-term MACE compared with unsuccessful CTO PCI.[31,32] While we did not examine long-term MACE, our findings of lower rates of technical success in adults aged ≥75 years compared with adults <75 years are consistent with these studies. Although differences in technical success were partially explained by prior bypass to the target vessel and re-attempt CTO PCI, age ≥75 remained associated with lower technical success rates after multivariable adjustment. Factors outside of anatomic complexity, such as age-associated changes to the mechanical and structural properties of the coronary vasculature, may explain the residual differences in technical success we observed. Moreover, we found that rates of technical success and MACE in adults ≥75 years were lower than that observed in PROGRESS CTO, which may be explained by differences in study design; namely, the consecutive, nonselective enrollment of patients (which likely reduced the risk of selection bias) and core laboratory adjudication of PCI technical success in OPEN-CTO.

With a lower likelihood of technical success and potentially higher complication rates, older adults may be less likely to be offered CTO PCI, suggesting a possible risk-averse treatment pattern. For instance, Hanan et al observed disproportionately fewer adults aged ≥70 years receiving CTO-PCI relative to adults <70 years in New York state from 2009 to 2012.[11] While data on contemporary trends in CTO treatment rates of older adults in the United States are lacking, this finding is particularly concerning as the population of adults aged ≥75 years is expected to double by 2050, and almost 4 in 10 individuals with coronary artery disease ≥65 years has at least 1 CTO.[1,2] In light of the substantial health status improvements in older adults enrolled in OPEN CTO, avoiding CTO PCI in individuals based on age alone could lead to significant undertreatment. Despite lower success rates and potentially higher adverse events, the increased risks of performing CTO PCI in older adults must be contextualized in the setting of compelling health status improvements with successful treatment. Because older adults often value symptom improvement, functional independence, and QOL more than life expectancy when considering treatment decisions,[12,13] CTO PCI may be an appealing treatment despite the increased risks. These data offer insights that may help better inform discussions of risk and benefit between providers and patients considering CTO PCI to ensure that treatment strategy is well aligned with patients' goals and values. Ideally, shared decision-making for CTO PCI in older adults should incorporate results from our study and technical success and complication risk prediction tools, such as the CASTLE technical success score[33] and the PROGRESS-CTO complication score.[34]

The health status measures used in this study may further contextualize the treatment benefits of CTO PCI in older adults. First, we found that although angina frequency was similar between adults aged ≥75 to <75 years, adults ≥75 years had significantly more physical limitations because of angina. These findings

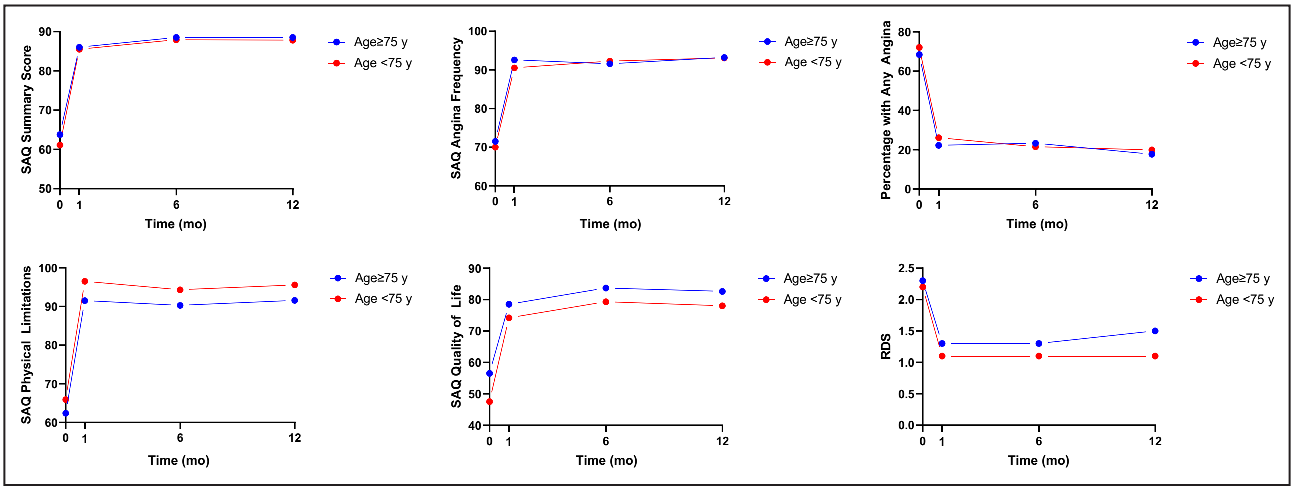

Figure 1. Unadjusted health status outcomes at baseline, 1, 6, and 12 months.
At 12 months, adults aged ≥75 years had lower SAQ Physical Limitations scores (*P*=0.002) and more dyspnea (*P*=0.001) but overall better SAQ Quality of Life scores (*P*=0.01). SAQ Summary Scores (*P*=0.57), SAQ Angina Frequency scores (*P*=0.95), and percentage of patients with any angina (*P*=0.50) were similar. RDS indicates Rose Dyspnea Scale; and SAQ; and Seattle Angina Questionnaire.

highlight the physically debilitating nature of angina in older adults with CTOs, who have potentially much to gain from preserving their physical function with revascularization. Although we observed a nonsignificant trend towards less improvement in physical functioning after CTO-PCI in adults aged ≥75 years compared with <75 years with our models at 12 months, older adults still had significant improvements with CTO PCI compared with baseline. Second, despite the similar treatment benefits in all SAQ domains between age groups, adults ≥75 years had less reduction in dyspnea than adults ≤75 years despite covariate adjustment (Figure 2). However, this difference in RDS score (change in RDS=0.2) may be because of residual unmeasured confounding, and is unlikely to be clinically meaningful as an RDS change equal to 1.0 has been demonstrated to represent a clinically important difference.[23] Of note, there was no significant difference in the proportion of individuals without angina but who had dyspnea in adults aged ≥75 versus <75 years (70.0% versus 63.8%), suggesting that older adults were not more likely to have dyspnea as an anginal equivalent. Therefore, quantifying the extent of dyspnea in participants without angina, independent of age, is crucial for identifying patients that would potentially benefit from CTO PCI. Third, the health status improvement following CTO PCI in adults aged ≥75 years was sustained through 12 months. Whether these health status benefits persist past 12 months is uncertain, but studies examining the durability of health status benefits in older adults undergoing PCI for stable CAD show more rapid declines in physical function after revascularization than younger adults after 12 months.[35] Further studies are needed to clarify the durability of these results.

Limitations

These findings should be interpreted in the context of certain potential limitations. With all observational studies, there is the potential for unmeasured confounding. However, any differences in health status between adults aged ≥75 to <75 years were shifted towards the

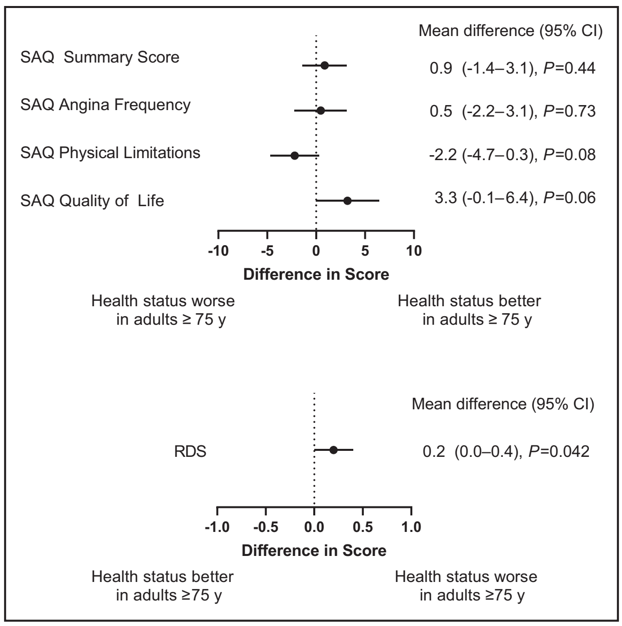

Figure 2. Adjusted difference in health status outcomes in patients aged ≥75 versus <75 years at 12 months.
Top panel: Difference in Seattle Angina Questionnaire Summary Score and SAQ domains. Positive values indicated better angina-related health status in patients aged ≥75 years compared with <75 years. Bottom panel: Difference in Rose Dyspnea Scale score. Positive values indicate more dyspnea in adults aged ≥75 years compared with <75 years. RDS indicates Rose Dyspnea Scale; and SAQ, Seattle Angina Questionnaire.

null with our models, suggesting little residual confounding. Second, frailty, cognitive status, or functional independence are important geriatric conditions that were not collected in OPEN-CTO, limiting our ability to examine their influence on health status, especially on physical functioning. Third, although a major strength of the OPEN-CTO study is the validated, consecutive enrollment of participants, the possibility for residual selection bias persists since older adults with prohibitive risk, limited life expectancy, poor independence, or marginal expected benefit may not have been referred for CTO PCI to begin with. Fourth, this study reflects the experience of 12 highly experienced hybrid centers, and as health status outcomes are influenced by technical success, our findings may not be generalizable to less experienced centers or operators. Fifth, as the primary purpose of this study was to examine health status outcomes in older adults, we did not study long-term MACE. Given the increasing importance and growth of ≥75-year-old population, evaluating long-term MACE after CTO PCI in this population warrants further study. Lastly, because of the observational nature of this study, we were not able to examine the impact of age on the health status benefits of CTO-PCI versus optimal medical therapy.

CONCLUSIONS

The decision to perform CTO-PCI in older adults can be challenging due to higher complication rates and lower rates of technical success. Despite these challenges, adults aged ≥75 years have rapid and sustained improvements in angina-related health status at 12 months that were similar to patients aged <75 years. Our study highlights the utility of CTO-PCI performed at experienced centers in improving symptoms, physical functioning, and QOL in older adults. At experienced centers, advanced age should not be considered a barrier to offering CTO PCI to otherwise appropriate candidates.

APPENDIX

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Supplemental Material

Tables S1–S6

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SUPPLEMENTAL MATERIAL

Table S1. Baseline characteristics in adults <65, 65-74, and ≥75 years old.

	Age <65 n = 467	Age 65-74 n = 335	Age ≥75 n = 198	Total n = 1000	P-Value
Demographics					
Age	56.5 ± 6.3	69.3 ± 2.7	79.5 ± 4.1	65.4 ± 10.3	< 0.001
Female Sex	84 (18.0%)	55 (16.4%)	57 (28.8%)	196 (19.6%)	0.001
Race					0.59
White	414 (88.7%)	305 (91.0%)	183 (92.4%)	902 (90.2%)	
Black	22 (4.7%)	11 (3.3%)	6 (3.0%)	39 (3.9%)	
Other	31 (6.6%)	19 (5.7%)	9 (4.5%)	59 (5.9%)	
Comorbidities					
BMI	31.5 ± 6.2	30.5 ± 6.0	28.1 ± 5.0	30.5 ± 6.0	< 0.001
Current smoker	94 (20.3%)	31 (9.4%)	8 (4.1%)	133 (13.4%)	< 0.001
History of Diabetes Mellitus	191 (40.9%)	141 (42.1%)	80 (40.4%)	412 (41.2%)	0.91
History of CHF	101 (21.6%)	73 (21.8%)	55 (27.8%)	229 (22.9%)	0.19
History PAD	60 (12.8%)	71 (21.2%)	44 (22.2%)	175 (17.5%)	0.001
History of MI	225 (48.2%)	169 (50.4%)	90 (45.5%)	484 (48.4%)	0.53
History of Hypertension	389 (83.3%)	297 (88.7%)	172 (86.9%)	858 (85.8%)	0.09
History CKD	57 (12.2%)	40 (11.9%)	38 (19.2%)	135 (13.5%)	0.032
History of Atrial Fibrillation	40 (8.6%)	53 (15.8%)	60 (30.3%)	153 (15.3%)	< 0.001
History of Lung Disease	54 (11.6%)	57 (17.0%)	33 (16.7%)	144 (14.4%)	0.06
Prior PCI	314 (67.2%)	215 (64.4%)	127 (64.1%)	656 (65.7%)	0.62
History of CABG	127 (27.2%)	143 (42.7%)	95 (48.0%)	365 (36.5%)	< 0.001
History of Stroke	9 (1.9%)	12 (3.6%)	7 (3.5%)	28 (2.8%)	0.29
LV Systolic Function					0.46
None	283 (66.9%)	192 (63.8%)	116 (61.4%)	591 (64.7%)	
Mild	56 (13.2%)	54 (17.9%)	38 (20.1%)	148 (16.2%)	
Moderate	43 (10.2%)	29 (9.6%)	19 (10.1%)	91 (10.0%)	
Severe	41 (9.7%)	26 (8.6%)	16 (8.5%)	83 (9.1%)	
Labs					
eGFR (Median, IQR)	82.8 (69.0, 97.7)	72.5 (58.5, 89.2)	65.0 (54.0, 77.4)	76.8 (60.9, 92.3)	< 0.001
Hemoglobin	13.9 ± 1.7	13.6 ± 1.6	13.0 ± 1.7	13.6 ± 1.7	< 0.001

BMI, body mass index; CHF, congestive heart failure; PAD, peripheral artery disease; MI, myocardial infarction; CKD, chronic kidney disease; PCI, percutaneous coronary intervention; CABG, coronary artery bypass grafting; LV, left ventricle; eGFR, estimated glomerular filtration rate.

Table S2. Procedural characteristics and complications in adults <65, 65-74, and ≥75 years old.

	Age <65 n = 467	Age 65-74 n = 335	Age ≥75 n = 198	Total n = 1000	P-Value
Primary CTO Vessel					0.75
LM	5 (1.1%)	2 (0.6%)	1 (0.5%)	8 (0.8%)	
LCx/OM	72 (15.4%)	60 (17.9%)	37 (18.7%)	169 (16.9%)	
RCA/PDA/RPLV	286 (61.2%)	213 (63.6%)	116 (58.6%)	615 (61.5%)	
Diagonal	4 (0.9%)	3 (0.9%)	1 (0.5%)	8 (0.8%)	
LAD	100 (21.4%)	57 (17.0%)	43 (21.7%)	200 (20.0%)	
Mean J-CTO Score	2.2 ± 1.2	2.4 ± 1.3	2.4 ± 1.3	2.3 ± 1.2	0.042
Blunt Proximal Cap	286 (61.2%)	220 (65.7%)	130 (65.7%)	636 (63.6%)	0.35
Calcification	118 (25.3%)	127 (37.9%)	80 (40.4%)	325 (32.5%)	< 0.001
Bending ≥45°	250 (53.5%)	181 (54.0%)	112 (56.6%)	543 (54.3%)	0.77
Lesion Length ≥20mm	286 (61.2%)	209 (62.4%)	121 (61.1%)	616 (61.6%)	0.94
Previously attempted lesion	96 (20.6%)	76 (22.7%)	32 (16.2%)	204 (20.4%)	0.19
Vessel tortuosity	197 (42.2%)	161 (48.1%)	91 (46.0%)	449 (44.9%)	0.24
Lesion length (mm)	61.7 ± 27.7	60.6 ± 28.6	60.2 ± 30.2	61.0 ± 28.5	0.77
Prior Bypass to Target CTO Vessel	100 (21.4%)	121 (36.1%)	79 (39.9%)	300 (30.0%)	< 0.001
Successful crossing strategy					0.15
Antegrade wire escalation	190 (43.5%)	111 (36.3%)	74 (42.0%)	375 (40.8%)	
Antegrade dissection and re-entry	101 (23.1%)	75 (24.5%)	47 (26.7%)	223 (24.3%)	
Retrograde wire escalation	48 (11.0%)	28 (9.2%)	19 (10.8%)	95 (10.3%)	
Retrograde dissection and re-entry	98 (22.4%)	92 (30.1%)	36 (20.5%)	226 (24.6%)	
Technical success	419 (89.7%)	285 (85.1%)	159 (80.3%)	863 (86.3%)	0.003
Any non-CTO-PCI	66 (14.1%)	44 (13.1%)	27 (13.6%)	137 (13.7%)	0.92
Complete Revascularization	365 (78.3%)	243 (72.8%)	148 (75.5%)	756 (75.9%)	0.19
Periprocedural complications					
Perforation	22 (4.7%)	42 (12.5%)	24 (12.1%)	88 (8.8%)	< 0.001
Septal Hematoma	4 (0.9%)	7 (2.1%)	3 (1.5%)	14 (1.4%)	0.31
Pericardial Effusion	6 (1.3%)	14 (4.2%)	6 (3.0%)	26 (2.6%)	0.036
Hemodynamically Significant	2 (33.3%)	7 (50.0%)	4 (66.7%)	13 (50.0%)	0.52

Access Site Hematoma	20 (4.3%)	11 (3.3%)	12 (6.1%)	43 (4.3%)	0.31
Radiation Dermatitis	0 (0.0%)	0 (0.0%)	1 (0.5%)	1 (0.1%)	0.2
Contrast Nephropathy	3 (0.6%)	3 (0.9%)	2 (1.0%)	8 (0.8%)	0.81
Retroperitoneal Bleed	2 (0.4%)	0 (0.0%)	0 (0.0%)	2 (0.2%)	0.69
MACCE	17 (3.6%)	30 (9.0%)	18 (9.1%)	65 (6.5%)	0.002
Death during procedure	1 (0.2%)	1 (0.3%)	3 (1.5%)	5 (0.5%)	0.11
Death during hospitalization	1 (0.2%)	5 (1.5%)	3 (1.5%)	9 (0.9%)	0.08
Post-procedure MI	10 (2.1%)	12 (3.6%)	4 (2.0%)	26 (2.6%)	0.38
Emergency Surgery	1 (0.2%)	3 (0.9%)	2 (1.0%)	6 (0.6%)	0.3
Stroke	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	

Abbreviations: LAD, left anterior descending coronary artery; LCX, left circumflex coronary artery; LM, left main coronary artery; OM, obtuse marginal coronary artery; PDA, posterior descending coronary artery; RCA, right coronary artery; RPLV, right posterolateral ventricular coronary artery; MACCE, major adverse cardiovascular and cerebral event; MI, myocardial infarction.

Vessel tortuosity defined as one or more bends ≥90° or three or more bends 45° to 90°.

Table S3. Comparison of baseline characteristics and health status between included versus excluded patients in the health status analysis.

	Included n = 963	Excluded n = 37	Total n = 1000	P-Value
Demographics				
Age	65.3 ± 10.3	66.6 ± 10.6	65.4 ± 10.3	0.45
Female Sex	188 (19.5%)	8 (21.6%)	196 (19.6%)	0.75
Race				0.55
White	870 (90.3%)	32 (86.5%)	902 (90.2%)	
Black	37 (3.8%)	2 (5.4%)	39 (3.9%)	
Other	56 (5.8%)	3 (8.1%)	59 (5.9%)	
Comorbidities				
BMI	30.4 ± 5.9	30.9 ± 7.7	30.5 ± 6.0	0.67
Current smoker	126 (13.2%)	7 (18.9%)	133 (13.4%)	0.32
History of Diabetes Mellitus	391 (40.6%)	21 (56.8%)	412 (41.2%)	0.05
History of CHF	217 (22.5%)	12 (32.4%)	229 (22.9%)	0.16
History PAD	168 (17.4%)	7 (18.9%)	175 (17.5%)	0.82
History of MI	457 (47.5%)	27 (73.0%)	484 (48.4%)	0.002
History of Hypertension	823 (85.5%)	35 (94.6%)	858 (85.8%)	0.12
History CKD	126 (13.1%)	9 (24.3%)	135 (13.5%)	0.08
History of Atrial Fibrillation	145 (15.1%)	8 (21.6%)	153 (15.3%)	0.28
History of Lung Disease	139 (14.4%)	5 (13.5%)	144 (14.4%)	0.88
Prior PCI	629 (65.4%)	27 (73.0%)	656 (65.7%)	0.34
History of CABG	352 (36.6%)	13 (35.1%)	365 (36.5%)	0.86
History of Stroke	26 (2.7%)	2 (5.4%)	28 (2.8%)	0.28
Type of Angina				0.02
Stable	809 (92.4%)	23 (79.3%)	832 (91.9%)	
Unstable	67 (7.6%)	6 (20.7%)	73 (8.1%)	
LV Systolic Dysfunction				0.02
None	570 (64.9%)	21 (60.0%)	591 (64.7%)	
Mild	146 (16.6%)	2 (5.7%)	148 (16.2%)	
Moderate	87 (9.9%)	4 (11.4%)	91 (10.0%)	
Severe	75 (8.5%)	8 (22.9%)	83 (9.1%)	
Labs				
eGFR (Median, IQR)	77.1 (61.2, 92.5)	64.6 (54.6, 77.2)	76.8 (60.9, 92.3)	0.01
Hemoglobin	13.6 ± 1.6	13.2 ± 2.1	13.6 ± 1.7	0.13
Last HbA1c	7.0 ± 1.6	8.2 ± 2.5	7.0 ± 1.7	0.01
Medications				
Diuretic	366 (38.0%)	15 (40.5%)	381 (38.1%)	0.76
Beta Blocker	813 (84.4%)	35 (94.6%)	848 (84.8%)	0.09
Calcium Channel Blocker	228 (23.7%)	10 (27.0%)	238 (23.8%)	0.64
Ranolazine	141 (14.6%)	6 (16.2%)	147 (14.7%)	0.79
Baseline Health Status				
SAQ Summary Score	61.6 ± 22.5	59.6 ± 21.3	61.5 ± 22.5	0.61

SAQ Angina Frequency	70.3 ± 27.1	75.8 ± 25.0	70.5 ± 27.0	0.23
Any Angina	687 (71.3%)	23 (63.9%)	710 (71.1%)	0.33
SAQ Physical Limitations	65.2 ± 26.2	58.2 ± 26.6	65.0 ± 26.2	0.14
SAQ Quality of Life	49.2 ± 27.3	43.9 ± 26.2	49.1 ± 27.3	0.25
Rose Dyspnea Scale	2.2 ± 1.5	2.7 ± 1.4	2.2 ± 1.5	0.05

Abbreviations: BMI, body mass index; CHF, congestive heart failure; PAD, peripheral artery disease; MI, myocardial infarction; CKD, chronic kidney disease; PCI, percutaneous coronary intervention; CABG, coronary artery bypass grafting; LV, left ventricle; eGFR, estimated glomerular filtration rate; SAQ, Seattle Angina Questionnaire.

Table S4. Comparison of procedural characteristics and complications between patients included versus excluded in the health status analysis.

	Included n = 963	Excluded n = 37	Total n = 1000	P-Value
Primary CTO Vessel				0.42
LM	8 (0.8%)	0 (0.0%)	8 (0.8%)	
LCx/OM	164 (17.0%)	5 (13.5%)	169 (16.9%)	
RCA/PDA/RPLV	595 (61.8%)	20 (54.1%)	615 (61.5%)	
LAD	188 (19.5%)	12 (32.4%)	200 (20.0%)	
Diagonal	8 (0.8%)	0 (0.0%)	8 (0.8%)	
J-CTO Score				0.69
0	80 (8.3%)	1 (2.7%)	81 (8.1%)	
1	184 (19.1%)	6 (16.2%)	190 (19.0%)	
2	252 (26.2%)	10 (27.0%)	262 (26.2%)	
3	274 (28.5%)	12 (32.4%)	286 (28.6%)	
4	147 (15.3%)	6 (16.2%)	153 (15.3%)	
5	26 (2.7%)	2 (5.4%)	28 (2.8%)	
Mean J-CTO Score	2.3 ± 1.3	2.6 ± 1.2	2.3 ± 1.2	0.18
Blunt Proximal Cap	609 (63.2%)	27 (73.0%)	636 (63.6%)	0.23
Calcification	310 (32.2%)	15 (40.5%)	325 (32.5%)	0.29
Bending ≥45°	520 (54.0%)	23 (62.2%)	543 (54.3%)	0.33
Lesion Length ≥20mm	592 (61.5%)	24 (64.9%)	616 (61.6%)	0.68
Previously attempted lesion	197 (20.5%)	7 (18.9%)	204 (20.4%)	0.82
Vessel tortuosity	429 (44.5%)	20 (54.1%)	449 (44.9%)	0.25
Lesion length	61.0 ± 28.4	61.1 ± 30.0	61.0 ± 28.5	0.99
Prior Bypass to Target CTO Vessel	291 (30.2%)	9 (24.3%)	300 (30.0%)	0.44
Initial crossing strategy				0.77
Antegrade wire escalation	526 (54.6%)	21 (56.8%)	547 (54.7%)	
Antegrade dissection and re-entry	136 (14.1%)	3 (8.1%)	139 (13.9%)	
Retrograde wire escalation	128 (13.3%)	5 (13.5%)	133 (13.3%)	
Retrograde dissection and re-entry	173 (18.0%)	8 (21.6%)	181 (18.1%)	
Successful crossing strategy				0.19
Antegrade wire escalation	359 (40.4%)	16 (51.6%)	375 (40.8%)	
Antegrade dissection and re-entry	219 (24.7%)	4 (12.9%)	223 (24.3%)	
Retrograde wire escalation	94 (10.6%)	1 (3.2%)	95 (10.3%)	
Retrograde dissection and re-entry	216 (24.3%)	10 (32.3%)	226 (24.6%)	
Technical success	837 (86.9%)	26 (70.3%)	863 (86.3%)	0.003
Any non-CTO-PCI	130 (13.5%)	7 (18.9%)	137 (13.7%)	0.35
Complete Revascularization	732 (76.3%)	24 (64.9%)	756 (75.9%)	0.11
Total Contrast Used	260.5 ± 138.8	300.8 ± 155.8	262.0 ± 139.5	0.08
Total Radiation Air Kerma Used	2521.1 ± 1890.8	2870.0 ± 1693.1	2534.0 ± 1884.2	0.27
Total Procedure Time	119.8 ± 63.8	144.3 ± 75.3	120.7 ± 64.4	0.02
Periprocedural complications				
Perforation	77 (8.0%)	11 (29.7%)	88 (8.8%)	< 0.001

Septal Hematoma	13 (1.3%)	1 (2.7%)	14 (1.4%)	0.41
Pericardial Effusion	19 (2.0%)	7 (18.9%)	26 (2.6%)	< 0.001
Hemodynamically Significant	8 (42.1%)	5 (71.4%)	13 (50.0%)	0.38
Access Site Hematoma	40 (4.2%)	3 (8.1%)	43 (4.3%)	0.21
Radiation Dermatitis	1 (0.1%)	0 (0.0%)	1 (0.1%)	1.000
Contrast Nephropathy	7 (0.7%)	1 (2.7%)	8 (0.8%)	0.26
Retroperitoneal Bleed	2 (0.2%)	0 (0.0%)	2 (0.2%)	1.000
MACCE	52 (5.4%)	13 (35.1%)	65 (6.5%)	< 0.001
Death during procedure	0 (0.0%)	5 (13.5%)	5 (0.5%)	< 0.001
Death during hospitalization	0 (0.0%)	9 (24.3%)	9 (0.9%)	< 0.001
Post-procedure MI	22 (2.3%)	4 (10.8%)	26 (2.6%)	0.01
Emergency Surgery	3 (0.3%)	3 (8.1%)	6 (0.6%)	< 0.001
Stroke	0 (0.0%)	0 (0.0%)	0 (0.0%)	

Abbreviations: LAD, left anterior descending coronary artery; LCX, left circumflex coronary artery; LM, left main coronary artery; OM, obtuse marginal coronary artery; PDA, posterior descending coronary artery; RCA, right coronary artery; RPLV, right posterolateral ventricular coronary artery; MACCE, major adverse cardiovascular and cerebral event; MI, myocardial infarction.

Vessel tortuosity defined as one or more bends ≥90° or three or more bends 45° to 90°.

Table S5. Health status outcomes in adults <65, 65-74, and ≥75 years old.

	Age <65 n = 450	Age 65-74 n = 323	Age ≥75 n = 190	Total n = 963	P-Value
SAQ Summary Score					
Baseline	59.1 ± 21.9	63.7 ± 23.0	63.8 ± 22.6	61.6 ± 22.5	0.006
12-month	86.8 ± 16.4	89.0 ± 14.2	88.5 ± 14.8	87.9 ± 15.4	0.14
SAQ Angina Frequency					
Baseline	69.1 ± 25.6	71.2 ± 28.4	71.5 ± 28.2	70.3 ± 27.1	0.45
12-month	92.7 ± 16.9	93.6 ± 17.3	93.2 ± 18.2	93.1 ± 17.3	0.79
Any Angina					
Baseline	339 (75.3%)	218 (67.5%)	130 (68.4%)	687 (71.3%)	0.036
12-month	90 (22.0%)	53 (17.3%)	31 (17.7%)	174 (19.5%)	0.23
SAQ Physical Limitations					
Baseline	64.7 ± 26.5	67.6 ± 25.5	62.4 ± 26.5	65.2 ± 26.2	0.10
12-month	95.2 ± 12.3	96.1 ± 12.0	91.6 ± 18.1	94.9 ± 13.4	<0.001
SAQ Quality of Life					
Baseline	44.0 ± 26.3	52.3 ± 27.9	56.5 ± 26.3	49.2 ± 27.3	< 0.001
12-month	76.0 ± 24.2	80.6 ± 19.7	82.6 ± 18.4	78.9 ± 21.8	< 0.001
Rose Dyspnea Scale					
Baseline	2.3 ± 1.5	2.1 ± 1.5	2.3 ± 1.5	2.2 ± 1.5	0.08
12-month	1.1 ± 1.4	1.0 ± 1.3	1.5 ± 1.5	1.2 ± 1.4	0.005

Note that the health status outcomes presented in this table are for patients with at least one baseline and one follow-up health status assessment. Abbreviations: SAQ, Seattle Angina Questionnaire.

Table S6. Comparison of models for difference in 12- month health status.

	Model 1* (95% CI)	P-value*	Model 2[¥] (95% CI)	P-value[¥]
SAQ Summary Score	0.9 (-1.4, 3.1)	0.44	0.9 (-1.3, 3.2)	0.41
SAQ Angina Frequency	0.5 (-2.2, 3.1)	0.73	0.5 (-2.1, 3.2)	0.70
SAQ Physical Limitations	-2.2 (-4.7, 0.3)	0.08	-2.2 (-4.7, 0.3)	0.09
SAQ Quality of Life	3.3 (-0.1, 6.4)	0.06	3.3 (0.0, 6.5)	0.049
Rose Dyspnea Scale	0.2 (0.0, 0.4)	0.042	0.2 (0.0, 0.4)	0.046

Model 1 adjusted for sex, diabetes, congestive heart failure, chronic lung disease, prior myocardial infarction, chronic kidney disease, and whether technical success was achieved. Model 2 includes Model 1 covariates plus in-hospital MACCE. For SAQ domains, positive values indicate better health status in adults ≥75 years old and negative values indicate better health status in adults <75 years old. For RDS, negative values indicate better health status in adults ≥75 years old and positive values indicate better health status in adults <75 years old.