Published in final edited form as:

Can J Cardiol. 2016 December ; 32(12): 1433–1439. doi:10.1016/j.cjca.2016.04.007.

Impact of lesion age on outcomes of chronic total occlusion percutaneous coronary intervention: Insights from a contemporary US multicenter registry

Barbara A. Danek, MD¹, Aris Karatasakis, MD¹, Dimitri Karpaliotis, MD², Khaldoon Alaswad, MD³, Farouc A. Jaffer, MD, PhD⁴, Robert W. Yeh, MD, MBA⁵, Mitul P. Patel, MD⁶, John Bahadorani, MD⁶, William L. Lombardi, MD⁷, R. Michael Wyman, MD⁸, J. Aaron Grantham, MD⁹, David E. Kandzari, MD¹⁰, Nicholas J. Lembo, MD¹⁰, Anthony H. Doing, MD¹¹, Catalin Toma, MD¹², Jeffrey W. Moses, MD², Ajay J. Kirtane, MD², Ziad A. Ali, MD², Manish Parikh, MD², Santiago Garcia, MD¹³, Phuong-Khanh Nguyen-Trong¹, Judit Karacsonyi, MD¹, Aya J. Alame, BA¹, Pratik Kalsaria, MS¹, Craig Thompson, MD, MMSc¹⁴, Subhash Banerjee, MD¹, and Emmanouil S. Brilakis, MD, PhD¹

¹VA North Texas Health Care System and University of Texas Southwestern Medical Center, Dallas, TX

²Henry Ford Hospital, Detroit, MI

³Columbia University, New York, NY

⁴Massachusetts General Hospital, Boston, MA

⁵Beth Israel Deaconess Medical Center, Boston, MA

⁶VA San Diego Healthcare System and University of California San Diego, La Jolla, CA

⁷PeaceHealth St. Joseph Medical Center, Bellingham, WA

⁸Torrance Memorial Medical Center, Torrance, CA

⁹Mid America Heart Institute, Kansas City, MO

¹⁰Piedmont Heart Institute, Atlanta, GA

¹¹Medical Center of the Rockies, Loveland, CO

¹²University of Pittsburgh Medical Center, Pittsburgh, PA

¹³Minneapolis VA Health Care System and University of Minnesota, Minneapolis, MN

¹⁴Boston Scientific, Natick, MA

Abstract

Corresponding author: Emmanouil S. Brilakis, MD, PhD, Dallas VA Medical Center (111A), 4500 South Lancaster Road, Dallas, TX 75216, Tel: (214) 857-1547, Fax: (214) 302-1341, esbrilakis@gmail.com.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Background—We sought to determine the impact of lesion age on procedural techniques and outcomes of chronic total occlusion (CTO) percutaneous coronary intervention (PCI).

Methods—We examined the characteristics and outcomes of 394 CTO PCIs with data on lesion age, performed between 2012–2016 at 11 experienced US centers.

Results—Mean patient age was 66 ± 10 years and 85.6% of patients were men. Overall technical and procedural success were 90.1% and 87.5%, respectively. A major adverse cardiovascular event (MACE) occurred in 16 patients (4.1%). Mean and median lesion ages were 43 ± 62 months and 12 months [interquartile range 3–64 months], respectively. Patients were stratified into tertiles by lesion age (3–5, 5–36.3, and >36.3 months). Older lesion age was associated with older patient age (68 ± 8 vs. 65 ± 10 vs. 64 ± 11 years, $p=0.009$), prior coronary artery bypass grafting (62% vs. 42% vs. 30%, $p<0.001$) and moderate/severe calcification (75% vs. 53% vs. 59%, $p=0.001$). Older lesions more often required use of the retrograde approach and antegrade dissection/re-entry for successful lesion crossing. There was no difference in technical (87.8% vs. 89.6% vs. 93.0%, $p=0.37$) or procedural (86.3% vs. 87.4% vs. 89.0%, $p=0.80$) success, or the incidence of MACE (3.1% vs. 3.0% vs. 6.3%, $p=0.31$) for older vs. younger occlusions.

Conclusions—Older CTO lesions exhibit angiographic complexity and more frequently necessitate the retrograde approach or antegrade dissection/reentry. Older CTOs can be recanalized with high technical and procedural success rates and acceptable MACE. Lesion age appears unlikely to be a significant determinant of CTO PCI success.

Brief summary for electronic table of contents

We studied the impact of lesion age on outcomes of chronic total occlusion (CTO) percutaneous coronary intervention (PCI). Older lesion age was associated with older patient age, prior coronary artery bypass grafting, and moderate/severe calcification, and more often required the retrograde approach and antegrade dissection re-entry for successful crossing. There was no difference in technical or procedural success or MACE among the groups. Older CTOs can be recanalized with high success rates and acceptable MACE.

Introduction

Coronary chronic total occlusions (CTOs) are defined as 100% occlusions of at least 3-month duration, although it is sometimes challenging to precisely determine the time of the occlusion in the absence of prior coronary angiograms. Older CTOs have traditionally been associated with lower CTO percutaneous coronary intervention (PCI) success rates^{1,2} due to longer lesion length³ and higher degree of calcification.^{4–6} However, with novel equipment and techniques,^{7–9} success rates of CTO PCI have significantly improved. Whether the benefits of these techniques can be achieved among lesions of all ages has received limited study and formed the focus of the present investigation.

Methods

Study population

We examined the clinical and angiographic records of 1,383 patients who underwent CTO PCI between May 2012 and January 2016 at 11 US centers experienced in CTO PCI:

Appleton Cardiology, Appleton, Wisconsin; Columbia University, New York, New York; Henry Ford Hospital, Detroit, Michigan; Massachusetts General Hospital, Boston, Massachusetts; Medical Center of the Rockies, Loveland, Colorado; Piedmont Heart Institute, Atlanta Georgia; PeaceHealth St. Joseph Medical Center, Bellingham Washington; St. Luke's Health System's Mid-America Heart Institute, Kansas City, Missouri; Torrance Memorial Center, Torrance, California; VA North Texas Health Care System, Dallas, Texas, and VA San Diego Healthcare System, San Diego, California. Data collection was performed prospectively and retrospectively and recorded in a dedicated CTO database (PROGRESS CTO, Clinicaltrials.gov Identifier: NCT02061436).^{10–17} Some centers only enrolled patients during part of the study period due to participation in other studies. Table 1 shows the number of cases contributed by each center (labelled 1–11). The study protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki and was approved by the institutional review board of each site.

Definitions

Coronary CTOs were defined as coronary lesions with thrombolysis in myocardial infarction (TIMI) grade 0 flow of at least 3 months duration. Estimation of the duration of occlusion was clinical, based on the first onset of angina, prior history of myocardial infarction in the target vessel territory, or comparison with a prior angiogram. In cases where there was documentation of a prior angiogram showing the occlusion, the lesion age was estimated based on the date of the first appearance of the occlusion on angiography. Of the 1,383 records examined, 394 patients had solid clinical documentation of occlusion age (prior angiogram in 376 patients and clear clinical documentation in 18 patients) and were included in the present analysis.

Calcification was assessed by angiography as mild (spots), moderate (involving 50% of the reference lesion diameter) and severe (involving >50% of the reference lesion diameter). Moderate proximal vessel tortuosity was defined as the presence of at least 2 bends >70° or 1 bend >90° and severe tortuosity as 2 bends >90° or 1 bend >120° in the CTO vessel. Interventional collaterals were defined as collaterals considered amenable to crossing by a guidewire and a microcatheter by the operator. Procedures in which antegrade dissection or antegrade re-entry or both were used at any time were classified as antegrade dissection re-entry (ADR) procedures. A procedure was considered retrograde if an attempt was made to cross the lesion through a collateral vessel supplying the target vessel distal to the lesion.

Technical success of CTO PCI was defined as successful CTO revascularization with achievement of <30% residual diameter stenosis within the treated segment and restoration of TIMI grade 3 antegrade flow. Procedural success was defined as the combination of technical success with no in-hospital major adverse cardiac events (MACE). In-hospital MACE included any of the following adverse events prior to hospital discharge: death, myocardial infarction, recurrent symptoms requiring urgent repeat target vessel revascularization with PCI or coronary artery bypass graft surgery (CABG), tamponade requiring either pericardiocentesis or surgery, and stroke. Myocardial infarction (MI) was defined using the Third Universal Definition of Myocardial Infarction (type 4 MI).¹⁸

Statistical Analysis

Categorical variables are expressed as percentages and were compared using Pearson's chi-square test or Fisher's exact test. Continuous variables are presented as mean $\pm$ standard deviation or median (interquartile range) unless otherwise specified and were compared using the t-test or Wilcoxon rank-sum test, as appropriate. All statistical analyses were performed with JMP 12.0 (SAS Institute, Cary, North Carolina). A two-sided p -value of 0.05 was considered statistically significant.

Results

Baseline clinical and angiographic characteristics

A total of 394 CTO PCIs performed in 394 patients were included in the present analysis of lesion age. Mean age of the study patients was 66 ± 10 years, and 86% were men with high prevalence of hypertension (88%), hyperlipidemia (96%), and diabetes mellitus (43%) (Table 2).

The mean and median lesion ages were 43 ± 62 and 12 [interquartile range 3–64] months, respectively (Figure 1). Patients were stratified into tertiles by lesion age (3–5 months, 5 to 36.3 months, and >36.3 months) with 128, 135, and 131 patients in each respective group. The slight differences in group size occurred because several patients had the same lesion age at the border between tertiles. Older lesion age was associated with older patient age (68 ± 8 vs. 65 ± 10 vs. 64 ± 11 years, $p=0.009$), prior coronary artery bypass graft surgery (62% vs. 42% vs. 30%, $p<0.001$) and moderate or severe calcification (75% vs. 53 vs. 59%, $p=0.001$).

Procedural characteristics and outcomes

The first crossing strategy used was antegrade wiring in 61%, retrograde in 28%, and antegrade dissection re-entry in 11%, with no significant difference in initial strategy according to lesion age (Table 3). The successful crossing strategy was antegrade wiring in 34%, retrograde in 34%, antegrade dissection re-entry in 24% (crossing failed in 9%). Older lesions were more frequently successfully recanalized using an antegrade dissection re-entry or the retrograde approach, and less frequently using antegrade wire escalation ($p=0.008$) (Figure 2). Overall use of antegrade dissection re-entry increased with increasing lesion age (46% vs. 36% vs. 30%, $p=0.026$) but overall use of the retrograde approach did not reach significant difference among the three groups (61% vs. 50% vs. 53%, $p=0.19$). Intravascular ultrasound (IVUS) was used in 40%, in both more recent and older lesions. Older lesions tended to require longer fluoroscopy time (75 ± 36 vs. 64 ± 40 vs. 64 ± 42 minutes, $p=0.043$), and higher patient air kerma dose (4.8 ± 2.5 vs. 4.0 ± 2.5 vs. 3.3 ± 2.1 Gray, $p=0.001$) (Figure 3). Procedure time and contrast volume did not differ significantly among the groups.

Overall technical success was 90.1%; overall procedural success was 87.5%; overall MACE was 4.1%. There was no difference in technical (87.8% vs. 93.0% vs. 89.6%, $p=0.37$) or procedural (86.3% vs. 87.4% vs. 89.0%, $p=0.80$) success, or the incidence of major adverse cardiac events (MACE, 6.3% vs. 3.0% vs. 3.1%, $p=0.31$) for older vs. more recent occlusions. There were 8 cases of MACE in the lowest tertile of lesion age: 3 perforations, 4

MIIs requiring re-PCI, and 1 ischemic stroke. The middle and highest lesion age tertiles had 4 cases of MACE each. MACE in the middle tertile comprised of perforation and ischemic stroke in 1 patient, 1 stent thrombosis requiring repeat PCI, and 2 myocardial infarctions, 1 of which was caused by donor artery damage. MACE in the highest tertile of lesion age was caused by 2 perforations causing tamponade and death, and 2 myocardial infarctions.

In addition, 728 lesions of unknown duration were compared with the 394 lesions of known age. Patients with known lesion age had higher incidence of prior PCI (75% vs. 57%, $p<0.001$), prior CABG (45% vs. 29%, $p<0.001$), prior MI (56% vs. 40%, $p<0.001$), and prior failed CTO PCI (28% vs. 12%, $p<0.001$) as compared with those of unknown lesion age. Lesions of known age tended to be more complex, with greater incidence of proximal cap ambiguity (38% vs. 28%, $p=0.001$) and higher J-CTO score (1.9 ± 1.0 vs. 1.7 ± 0.9 , $p<0.001$). Interventional collaterals were more common among lesions of known age (66% vs. 54%, $p<0.001$). There was no difference in technical or procedural success, but fluoroscopy time and procedure time were longer in the known lesion age group (67 ± 39 vs. 46 ± 31 min, $p<0.001$; 170 ± 91 vs. 135 ± 83 min, $p<0.001$, respectively). MACE was higher among patients with lesions of known duration (4.1% vs. 1.9%, $p=0.034$).

Discussion

The main findings of our study are that older CTOs: a) are more anatomically complex than more recent CTOs, with a higher prevalence of moderate/severe calcification; b) more frequently require use of the retrograde approach and antegrade dissection/re-entry for crossing; yet c) similarly to more recent occlusions, they can be successfully recanalized in approximately 90% of cases with similar MACE rates, although they may require longer fluoroscopy time and radiation dose.

Prior studies have shown an association between lesion age and severity of calcification. Study of post-mortem CTO lesion morphology has shown age-related differences in occlusion histologic composition. Srivatsa et al studied 96 CTOs from autopsies in 61 patients and found that cholesterol and foam cells were seen more frequently in younger lesions, while older lesions tended to have a greater fibrocalcific component.⁶ Sakakura et al studied 96 CTO lesions from 82 patients with and without prior CABG; lesions from patients without CABG were stratified by occlusion duration. The prior CABG group showed the most calcification (29% calcified area at CTO segment), followed by the long-duration CTO group (17% calcified area), while the short-duration CTO group was associated with microvessels and loose fibrous tissue (12% calcified area).⁵ An IVUS study by Suzuki et al. also demonstrated increasing calcification with increasing CTO age (correlation between arc of calcification and lesion age $r=0.445$, $p<0.0001$; correlation between length of calcification and lesion age $r=0.397$, $p=0.001$).¹⁹

Apart from calcification, older lesions were more prevalent among prior CABG patients. Prior CABG has been associated with higher procedural complexity and lower success rates,²⁰ although more recently we have demonstrated that similarly high success rates can be achieved among patients with and without prior CABG.²¹ Achieving similarly high success rates among older lesions may in part be explained by use of the hybrid approach,

which advocates early change of crossing strategy in case the initially selected approach does not provide prompt results.⁹ Another explanation is the availability and use of advanced CTO crossing techniques (retrograde approach and antegrade dissection/re-entry), especially in older (and more complex) lesions. It could also be related to participation of experienced CTO PCI centers and operators in our registry.²²

Contemporary studies of the impact of CTO age on procedural outcomes have yielded mixed results. Barlis et al showed that indeterminate CTO age independently predicts CTO PCI failure with an odds ratio of 4.51 ($p=0.002$).²³ Our findings actually suggest the opposite: lesions of unknown age tended to be less complex, but were associated with equal technical and procedural success as lesions of known age. Known lesion age may be a proxy for more advanced cardiovascular disease and more experience with diagnostic procedures and treatment, including failed CTO PCI, which has been associated with higher lesion complexity.²⁴

Tomasello and colleagues recently showed that CTOs of longer duration (>12 months) and indeterminate duration can be treated with no impact on procedural outcomes and one-year MACE.²⁵ The presence of severe calcifications, longer CTO length, and small vessel diameter were independent predictors of technical failure.²⁵ Our findings are in agreement with those of Tomasello et al., suggesting that revascularization of older CTOs can be safely and effectively attempted.

Our study is limited by its partly retrospective design and observational nature. As a registry, the strengths of our study include the large number of cases, the 'real-world' setting, and the inclusion of high-risk groups that are often excluded from randomized trials.²⁶ Moreover, there is currently limited randomized data regarding CTO revascularization, underscoring the importance of observational data in this field. However, the robustness of registry-derived data may be limited by the presence of expected and unexpected confounders, and as such must be interpreted thoughtfully. A randomized trial assessing outcomes of CTO PCI on lesions of different age would further strengthen our conclusions.

The lack of precise dating of lesion age is another potential limitation, although we only included cases with angiographic or solid clinical documentation of lesion age in our analysis. Determining the exact age of a CTO is very challenging, as serial coronary artery imaging is infrequently performed and even when it is performed the exact onset of the occlusion is often unclear. Therefore it is likely that reported occlusion ages underestimate the true age of the occlusion. We excluded CTOs whose duration could not be assessed, which may have introduced case selection bias. This possibility is suggested by the fact that cases with lesions of known age were significantly more clinically and angiographically complex than lesions of unknown age. The current study may be not be fully powered to determine if significant differences in success rates based on lesion age are present; however the absolute differences (5.2% between tertiles) seen here are small, and the overall success rates (87.8–93%) are acceptable. Finally, the predominantly male study population may limit extrapolation of the findings to women.

Conclusions

Despite increased angiographic complexity driven mainly by calcification, older CTOs can be recanalized with high technical and procedural success and acceptable MACE rates, and therefore lesion age appears unlikely to be a significant determinant of the success of CTO PCI.

Acknowledgments

Study data were collected and managed using REDCap electronic data capture tools hosted at University of Texas Southwestern Medical Center. ¹REDCap (Research Electronic Data Capture) is a secure, web-based application designed to support data capture for research studies, providing 1) an intuitive interface for validated data entry; 2) audit trails for tracking data manipulation and export procedures; 3) automated export procedures for seamless data downloads to common statistical packages; and 4) procedures for importing data from external sources.

¹Paul A. Harris, Robert Taylor, Robert Thielke, Jonathon Payne, Nathaniel Gonzalez, Jose G. Conde, Research electronic data capture (REDCap) - A metadata-driven methodology and workflow process for providing translational research informatics support, J Biomed Inform. 2009 Apr; 42(2):377-81.

Supported by CTSA NIH Grant UL1-RR024982.

References

1. Kereiakes DJ, Selmon MR, McAuley BJ, McAuley DB, Sheehan DJ, Simpson JB. Angioplasty in total coronary artery occlusion: experience in 76 consecutive patients. J Am Coll Cardiol. 1985; 6:526–533. [PubMed: 3161923]
2. Melchior JP, Meier B, Urban P, et al. Percutaneous transluminal coronary angioplasty for chronic total coronary arterial occlusion. Am J Cardiol. 1987; 59:535–538. [PubMed: 2950747]
3. Morino Y, Abe M, Morimoto T, et al. Predicting successful guidewire crossing through chronic total occlusion of native coronary lesions within 30 minutes: the J-CTO (Multicenter CTO Registry in Japan) score as a difficulty grading and time assessment tool. JACC Cardiovasc Interv. 2011; 4:213–221. [PubMed: 21349461]
4. Irving J. CTO pathophysiology: how does this affect management? Curr Cardiol Rev. 2014; 10:99–107. [PubMed: 24694103]
5. Sakakura K, Nakano M, Otsuka F, et al. Comparison of pathology of chronic total occlusion with and without coronary artery bypass graft. Eur Heart J. 2014; 35:1683–1693. [PubMed: 24126875]
6. Srivatsa SS, Edwards WD, Boos CM, et al. Histologic correlates of angiographic chronic total coronary artery occlusions: influence of occlusion duration on neovascular channel patterns and intimal plaque composition. J Am Coll Cardiol. 1997; 29:955–963. [PubMed: 9120181]
7. Michael TT, Papayannis AC, Banerjee S, Brilakis ES. Subintimal dissection/reentry strategies in coronary chronic total occlusion interventions. Circ Cardiovasc Interv. 2012; 5:729–738. [PubMed: 23074346]
8. El Sabbagh A, Patel VG, Jeroudi OM, et al. Angiographic success and procedural complications in patients undergoing retrograde percutaneous coronary chronic total occlusion interventions: a weighted meta-analysis of 3,482 patients from 26 studies. Int J Cardiol. 2014; 174:243–248. [PubMed: 24768461]
9. Brilakis ES, Grantham JA, Rinfret S, et al. A percutaneous treatment algorithm for crossing coronary chronic total occlusions. JACC Cardiovasc Interv. 2012; 5:367–379. [PubMed: 22516392]
10. Alaswad K, Menon RV, Christopoulos G, et al. Transradial approach for coronary chronic total occlusion interventions: Insights from a contemporary multicenter registry. Catheter Cardiovasc Interv. 2015; 85:1123–1129. [PubMed: 25640902]
11. Christopoulos G, Karpaliotis D, Alaswad K, et al. The efficacy of "hybrid" percutaneous coronary intervention in chronic total occlusions caused by in-stent restenosis: insights from a US multicenter registry. Catheter Cardiovasc Interv. 2014; 84:646–651. [PubMed: 24585508]

12. Christopoulos G, Karpaliotis D, Wyman MR, et al. Percutaneous Intervention of Circumflex Chronic Total Occlusions Is Associated With Worse Procedural Outcomes: Insights From a Multicentre US Registry. *Can J Cardiol*. 2014; 30:1588–1594. [PubMed: 25442459]
13. Christopoulos G, Menon RV, Karpaliotis D, et al. The efficacy and safety of the "hybrid" approach to coronary chronic total occlusions: insights from a contemporary multicenter US registry and comparison with prior studies. *J Invasive Cardiol*. 2014; 26:427–432. [PubMed: 25198485]
14. Christopoulos G, Menon RV, Karpaliotis D, et al. Application of the "hybrid approach" to chronic total occlusions in patients with previous coronary artery bypass graft surgery (from a Contemporary Multicenter US registry). *Am J Cardiol*. 2014; 113:1990–1994. [PubMed: 24793678]
15. Sapontis J, Christopoulos G, Grantham JA, et al. Procedural failure of chronic total occlusion percutaneous coronary intervention: Insights from a multicenter US registry. *Catheter Cardiovasc Interv*. 2015; 85:1115–1122. [PubMed: 25557905]
16. Christopoulos G, Wyman RM, Alaswad K, et al. Clinical Utility of the Japan-Chronic Total Occlusion Score in Coronary Chronic Total Occlusion Interventions: Results from a Multicenter Registry. *Circ Cardiovasc Interv*. 2015; 8:e002171. [PubMed: 26162857]
17. Christopoulos G, Karpaliotis D, Alaswad K, et al. Application and outcomes of a hybrid approach to chronic total occlusion percutaneous coronary intervention in a contemporary multicenter US registry. *Int J Cardiol*. 2015; 198:222–228. [PubMed: 26189193]
18. Thygesen K, Alpert JS, Jaffe AS, et al. Third universal definition of myocardial infarction. *Glob Heart*. 2012; 7:275–295. [PubMed: 25689940]
19. Suzuki T, Hosokawa H, Yokoya K, et al. Time-dependent morphologic characteristics in angiographic chronic total coronary occlusions. *Am J Cardiol*. 2001; 88:167–169. A5–A6. [PubMed: 11448416]
20. Teramoto T, Tsuchikane E, Matsuo H, et al. Initial success rate of percutaneous coronary intervention for chronic total occlusion in a native coronary artery is decreased in patients who underwent previous coronary artery bypass graft surgery. *JACC Cardiovasc Interv*. 2014; 7:39–46. [PubMed: 24456717]
21. Michael TT, Karpaliotis D, Brilakis ES, et al. Impact of prior coronary artery bypass graft surgery on chronic total occlusion revascularisation: insights from a multicentre US registry. *Heart*. 2013; 99:1515–1518. [PubMed: 23598543]
22. Michael TT, Karpaliotis D, Brilakis ES, et al. Temporal trends of fluoroscopy time and contrast utilization in coronary chronic total occlusion revascularization: insights from a multicenter united states registry. *Catheter Cardiovasc Interv*. 2015; 85:393–399. [PubMed: 24407867]
23. Barlis P, Kaplan S, Dimopoulos K, Tanigawa J, Schultz C, Di Mario C. An indeterminate occlusion duration predicts procedural failure in the recanalization of coronary chronic total occlusions. *Catheter Cardiovasc Interv*. 2008; 71:621–628. [PubMed: 18360843]
24. Karacsonyi J, Karatasakis A, Karpaliotis D, et al. Effect of Previous Failure on Subsequent Procedural Outcomes of Chronic Total Occlusion Percutaneous Coronary Intervention (from a Contemporary Multicenter Registry). *Am J Cardiol*. 2016
25. Tomasello SD, Costanzo L, Campisano MB, et al. Does occlusion duration influence procedural and clinical outcome of patients who underwent percutaneous coronary intervention for chronic total occlusion? *J Interv Cardiol*. 2011; 24:223–231. [PubMed: 21309854]
26. Gitt AK, Bueno H, Danchin N, et al. The role of cardiac registries in evidence-based medicine. *Eur Heart J*. 2010; 31:525–529. [PubMed: 20093258]

Figure 1.
The distribution of lesion age in the study cohort.

Figure 2.
Association between lesion age and successful crossing strategy.

Figure 3. Association between lesion age and fluoroscopy time (panel A) and patient air kerma dose (panel B).

Table 1

Case volume per CTO PCI center

Center	Number of cases contributed during the study period
1	221
2	177
3	165
4	141
5	130
6	124
7	115
8	94
9	89
10	77
11	50
Overall	1383

Table 2

Clinical and angiographic characteristics according to lesion age

Variable	Overall	1st tertile	2nd tertile	3rd tertile	<i>p</i>
Clinical Characteristics					
	n=394	n=128	n=135	n=131	
Age (years)	65.8 ± 9.9	64.4 ± 10.7	65.0 ± 10.0	68.2 ± 8.3	0.009
Men (%)	85.6	85.6	81.3	89.9	0.141
Hypertension (%)	88.2	84.7	92.5	87.0	0.131
Hyperlipidemia (%)	95.6	93.6	94.8	98.5	0.135
Diabetes mellitus (%)	43.3	39.2	40.3	50.4	0.134
Current tobacco use (%)	14.0	20.3	8.9	13.0	0.026
Heart failure (%)	29.4	27.2	31.8	28.9	0.713
Prior MI (%)	55.4	47.2	58.0	60.8	0.073
Prior CABG (%)	44.9	29.6	42.1	62.3	<0.001
Prior stroke (%)	12.1	11.4	15.7	9.2	0.256
Prior PCI (%)	75.1	72.8	71.6	80.9	0.167
Prior CTO PCI failure (%)	27.7	30.5	26.9	26.0	0.692
Peripheral arterial disease (%)	15.5	13.8	17.9	14.5	0.619
Angiographic characteristics					
CTO target vessel					0.315
RCA (%)	60.8	61.0	59.5	61.9	
LCX (%)	21.1	17.1	20.6	25.4	
LAD (%)	17.9	21.1	19.8	12.7	
CTO length (mm) *	34.4 ± 25.0	35.3 ± 25.0	32.0 ± 24.7	35.9 ± 25.4	0.383
Interventional collaterals (%)	65.5	67.5	59.1	70.1	0.151
Moderate/severe calcification (%)	62.5	59.0	53.4	75.0	0.001
Moderate/severe tortuosity (%)	35.1	35.6	30.0	39.8	0.251

Variable	Overall	1st tertile	2nd tertile	3rd tertile	p
Proximal cap ambiguity (%)	37.9	35.0	35.6	43.0	0.342
In-stent restenosis (%)	14.9	16.7	18.7	9.2	0.078
J-CTO score *	2.9 ± 1.2	2.8 ± 1.1	2.6 ± 1.2	2.9 ± 1.0	0.091
PROGRESS CTO score *	1.6 ± 0.8	1.5 ± 0.8	1.7 ± 0.8	1.6 ± 0.8	0.249

* mean ± standard deviation

CTO, chronic total occlusion; PCI, percutaneous coronary intervention; MI, myocardial infarction; CABG, coronary artery bypass grafting; RCA, right coronary artery; LCX, left circumflex coronary artery; LAD, left anterior descending coronary artery

Table 3

Procedural characteristics and outcomes according to lesion age

Variable	Overall	1 st tertile	2 nd tertile	3 rd tertile	p
Procedural characteristics					
	n=394	n=128	n=135	n=131	
First crossing strategy					0.598
Antegrade wiring (%)	61.2	64.1	63.7	55.7	
Antegrade dissection re-entry (%)	11.2	9.4	10.4	13.7	
Retrograde (%)	27.7	26.6	25.9	30.5	
Successful crossing strategy					0.008
Antegrade wiring (%)	33.8	39.8	40.0	21.4	
Antegrade dissection re-entry (%)	24.1	18.8	25.9	27.5	
Retrograde (%)	33.5	35.2	25.9	39.7	
None (%)	8.6	6.3	8.2	11.5	
IVUS used (%)	40.3	45.8	38.0	36.5	0.492
Stenting (%)	88.5	91.4	87.4	86.8	0.454
Number of stents *	2.6 ± 1.1	2.5 ± 1.1	2.6 ± 1.2	2.8 ± 1.2	0.095
Fluoroscopy time (min) *	67.3 ± 39.3	63.7 ± 41.5	63.9 ± 39.5	74.5 ± 36.2	0.043
Patient air kerma dose (Gray) *	2.1 ± 1.9	3.3 ± 2.1	4.0 ± 2.5	4.8 ± 2.5	0.001
Procedure time (min) *	169.8 ± 90.9	159.0 ± 88.7	170.2 ± 103.4	179.6 ± 78.0	0.200
Contrast volume (mL) *	283.1 ± 124.6	265.5 ± 127.6	286.1 ± 121.1	297.2 ± 124.3	0.122
Outcomes					
Technical success (%)	90.1	93.0	89.6	87.8	0.368
Procedural success (%)	87.5	89.0	87.4	86.3	0.803
MACE (%)	4.1	6.3	3.0	3.1	0.311
Death (%)	0.8	0.8	0	1.5	0.359
Myocardial infarction (%)	1.8	2.3	1.5	1.5	0.839
Stroke (%)	0.5	0.8	0.7	0	0.606
Emergency re-PCI (%)	0.8	1.6	0.7	0	0.351

Variable	Overall	1 st tertile	2 nd tertile	3 rd tertile	<i>p</i>
Emergency CABG (%)	-	-	-	-	-
Emergency percutaneous intervention (%)	0.8	1.6	0	0.8	0.346

* mean ± standard deviation

IVUS, intravascular ultrasound; MACE, major adverse cardiac event; PCI, percutaneous coronary intervention; CABG, coronary artery bypass grafting