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doi:10.1016/j.jcin.2009.02.008

This information is current as of November 21, 2009

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Chronic Total Occlusion Angioplasty in the United States

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Coronary chronic total occlusions (CTOs) are commonly encountered complex lesions identified in 15% of all patients referred for coronary angiography. Chronic total occlusion remains the most powerful predictor of referral for coronary bypass surgery. The benefits of CTO percutaneous coronary intervention (PCI) include symptom relief, improved left ventricular function, and potentially a survival advantage associated with success when compared with failed CTO-PCI. Data from the NCDR (National Cardiovascular Data Registry) suggest that CTO-PCI attempt rates in the U.S. have not changed over the past 5 years despite significant advances in techniques and technology, some of which we review here. Additionally, these data highlight a major disparity in attempt rates based on operator PCI volume. Remaining barriers to attempting CTO-PCI in the U.S. include operator inexperience, the perception of increased risk of CTO-PCI, and financial disincentives to operators and hospitals. To overcome operator inexperience, participation in CTO clubs, the invitation of guest operators, and a dedicated CTO day can be implemented at institutions committed to learning advanced CTO-PCI techniques so that operators can overcome the barriers and offer patients access to percutaneous therapy when it is clinically indicated. (J Am Coll Cardiol Intv 2009;2:479–86) © 2009 by the American College of Cardiology Foundation

Coronary chronic total occlusions (CTOs) are commonly encountered complex lesions identified in 15% to 30% of all patients referred for coronary angiography (1,2). Chronic total occlusions have been referred to as the final frontier in interventional cardiology (3). This sentiment relates to the difficulty and complexity of recanalizing them with percutaneous techniques.

The difficulty in treating CTOs percutaneously is reflected in the observation that success rates are lower for CTO percutaneous coronary intervention (PCI) than for subtotal stenoses (70% vs. 98%) (4,5). Thus, this common and complex coronary occlusion remains the strongest independent predictor of referral for coronary artery bypass graft surgery (1). Additionally, CTO-PCI attempt rates are surprisingly low relative to estimates of angiographic suitability (2), and in 1 series (6), the frequency of CTO-PCI relative to all PCI is decreasing. The purpose of this review is to summarize the benefits of CTO-PCI, review current practice patterns in an effort to identify common barriers to attempting CTO-PCI among operators in the U.S., summarize emerging techniques, and suggest potential options for learning these techniques so that operators can overcome the barriers and offer patients access to percutaneous therapy when it is clinically indicated.

Benefits of CTO-PCI

CTO-PCI has the potential to offer patients several benefits including symptom relief, improve-
ment in left ventricular function, and better long-term survival.

**Symptom relief.** Successful CTO-PCI is associated with improved symptom relief when compared with unsuccessful CTO-PCI (7). In the TOAST-GISE (Total Occlusion Angioplasty–Società Italiana di Cardiologia Invasiva) trial, CTO-PCI success was associated with 86% angina-free survival, whereas CTO-PCI failure was associated with 70% angina-free survival ($p = 0.008$). Cheng et al. (8) demonstrated that 76% of patients with CTO who were treated with PCI experienced an improved angina classification, whereas 17% of patients who were not treated with PCI improved ($p < 0.05$). No study to date has used a reliable instrument such as the Seattle Angina Questionnaire to quantify the benefits of CTO-PCI on quality-of-life outcomes.

**Left ventricular function.** Successful CTO-PCI has been demonstrated to result in improved left ventricular function and attenuated left ventricular remodeling as long as vessel patency is maintained (9–11). Cheng et al. (8) used contrast-enhanced magnetic resonance imaging to demonstrate that wall thickening in the myocardium subtended by a CTO vessel improved with CTO-PCI over the ensuing 6 months (55% to 68%). Others have suggested that patients who have never experienced a clinically evident myocardial infarction (MI) (9) or patients who have had an MI but have residual ischemia, viability, or hibernating myocardium are most likely to benefit from CTO-PCI (12,13). Identifying these latter patients can be difficult. Cardiac positron emission computed tomography (14), cardiac contrast-enhanced magnetic resonance imaging (8,15), and dobutamine echocardiography (14) appear to be promising imaging techniques to assess viability and may be useful in determining the appropriateness of PCI.

**Survival advantage.** The presence of an untreated CTO is prognostically important. Hannan et al. (16) used the New York State PCI registry to determine the association of completeness of revascularization after PCI and survival. After adjustment for baseline differences, the mortality rate was higher when incomplete revascularization was due to an untreated CTO than a subtotal stenosis (hazard ratio: 1.36, 95% confidence interval [CI]: 1.12 to 1.66; $p < 0.05$). Multivessel disease is associated with an increased risk of mortality in the setting of acute MI. The majority of this risk is attributable to the presence of a CTO (17).

The survival advantage associated with successful versus unsuccessful CTO-PCI has been demonstrated in unselected patients in 5 studies (5,7,18–20) (Table 1). A 3.8% to 8.4% absolute reduction in mortality was associated with successful versus failed CTO-PCI. Only 1 recent study (4) has failed to identify an association between successful CTO-PCI and improved survival.

Taken together, these studies support the hypothesis that successful CTO-PCI may be life-prolonging, a hypothesis that certainly deserves further testing in the form of a randomized controlled trial. Without such a trial, controversy will persist over the survival benefit of CTO-PCI. Until then, the decision to intervene in the absence of symptoms or heart failure remains difficult and controversial. Chronic total occlusion PCI in asymptomatic patients with normal left ventricular function and no or only mild ischemia in the distribution of the occluded vessel cannot be justified. Only in the case of prognostically significant ischemia or heart failure with significant viability should CTO-PCI be considered in the absence of symptoms.

**What Are the Barriers to Performing CTO-PCI?**

Despite conferring benefits, CTO-PCI attempt rates remain surprisingly low and unchanged over the past 5 years in the U.S. Historically, investigators estimated the frequency of CTO-PCI as a function of all PCIs performed. With that metric, 5% of all PCIs performed were done for CTO (6), but the true CTO attempt rate is unknown. The attempt rate can be approximated using both the cardiac catheterization and the PCI modules of the NCDR (National Cardiovascular Data Registry) database, which is restricted to U.S. centers (21). The CTO-PCI attempt rate among 388 participating centers is defined as the number of CTO-PCI attempts divided by the number of eligible CTOs discovered at the time of angiography. Between January 2004 and March 2005, 645,520 patients

### Table 1. Single-Center Studies of Survival in CTO-PCI Success Versus Failure

<table>
<thead>
<tr>
<th>Author (Ref. #)</th>
<th>n</th>
<th>Time Frame</th>
<th>Follow-Up Time</th>
<th>Survival in Success Versus Failed CTO-PCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Suero et al. (5)</td>
<td>2,007</td>
<td>1980–1999</td>
<td>Cumulative 10 yr</td>
<td>73.5 vs. 65.1%, $p = 0.001$</td>
</tr>
<tr>
<td>Hoye et al. (18)</td>
<td>874</td>
<td>1999–2002</td>
<td>4.47 ± 2.69</td>
<td>93.5 vs. 88.0%, $p = 0.020$</td>
</tr>
<tr>
<td>Aziz et al. (19)*</td>
<td>199</td>
<td>2000–2004</td>
<td>Cumulative 2 yr</td>
<td>98.0 vs. 94.2%, $p = 0.045$</td>
</tr>
<tr>
<td>Olivari et al. (7)†</td>
<td>369</td>
<td>2003</td>
<td>1 yr</td>
<td>98.9 vs. 96.4%, $p = 0.039$</td>
</tr>
<tr>
<td>Valenti et al. (20)</td>
<td>486</td>
<td>2003–2006</td>
<td>Cumulative 4 yr</td>
<td>91.6 vs. 87.4%, $p = 0.025$</td>
</tr>
</tbody>
</table>

*Includes only the propensity-matched cohort. †Cardiac death among patients discharged without myocardial infarction or coronary artery bypass grafting.

CTO = chronic total occlusion; PCI = percutaneous coronary intervention.
underwent diagnostic angiography, of which 35,643 were discovered to have a CTO and no indication for noncoronary cardiac surgery (e.g., valvular heart disease). A total of 4,828 patients ultimately underwent attempted CTO-PCI, yielding a national attempt rate of 13.6%. Among these patients, 6,523 (18.3%) were referred for bypass surgery during the same hospitalization. These analyses were extended to subsequent versions of the NCDR. As shown in Figure 1, the PCI attempt rate for CTOs has not changed over the past 5 years, despite major advances in procedural technique.

There may be patient- or operator-related barriers to CTO-PCI that explain this surprisingly low attempt rate. There were 2,632 operators from NCDR version 3.04 included in this analysis, 1,388 were low volume (<75 PCIs per year), 941 intermediate volume (75 to 200 PCIs per year), and 301 high volume (>200 PCIs per year). Table 2 lists the multivariate predictors of CTO-PCI attempt operators. Patient characteristics such as decreasing age, absence of diabetes, and single-vessel disease were associated with an increased CTO-PCI attempt operators. After adjustment for these differences, low- and intermediate-volume operators were one-half as likely as high-volume operators to perform CTO-PCI.

Figure 2 demonstrates the mean attempt rate in each volume strata. Not only was the mean attempt rate of all low-volume operators lower than that of intermediate- and high-volume operators, but also the standard deviation of the mean attempt rate was highest in the low-volume group. These observations suggest less variance in attempt rates among high-volume operators. Additionally, low-volume operators were more likely to refer patients with CTO for coronary artery bypass graft surgery (19.1%, 15.9%, and 14.0%, low, intermediate, and high, respectively; p < 0.001).

We also found that the vast majority of operators in the U.S. perform less than 200 PCIs per year. Therefore, the efforts of individual high-volume operators willing to embark on a more aggressive CTO program may be diluted by the majority of operators who are less enthusiastic about attempting these difficult cases (22). In addition to operator experience, there are several barriers to CTO-PCI that may contribute to operator reluctance to attempt these complex lesions. These include: 1) the difficulty in crossing CTOs with wires; 2) unique complications such as vessel perforation, contrast nephropathy, radiation injury, and

### Table 2. Independent Predictors of CTO-PCI Attempt

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Odds Ratio</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age by 10-yr decrease</td>
<td>1.34</td>
<td>1.31–1.38</td>
</tr>
<tr>
<td>Race: other vs. Caucasian</td>
<td>1.23</td>
<td>1.12–1.35</td>
</tr>
<tr>
<td>Nondiabetic</td>
<td>1.25</td>
<td>1.17–1.34</td>
</tr>
<tr>
<td>No prior MI</td>
<td>1.48</td>
<td>1.38–1.59</td>
</tr>
<tr>
<td>Creatinine &lt;2.0 mg/dl</td>
<td>1.93</td>
<td>1.57–2.38</td>
</tr>
<tr>
<td>Stress test result</td>
<td>1.18</td>
<td>1.07–1.31</td>
</tr>
<tr>
<td>Symptom status</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unstable angina vs. asymptomatic</td>
<td>1.78</td>
<td>1.63–1.96</td>
</tr>
<tr>
<td>Unstable angina vs. atypical chest pain</td>
<td>1.66</td>
<td>1.49–1.85</td>
</tr>
<tr>
<td>Unstable angina vs. stable angina</td>
<td>1.34</td>
<td>1.24–1.45</td>
</tr>
<tr>
<td>EF &gt;40%</td>
<td>1.26</td>
<td>1.15–1.38</td>
</tr>
<tr>
<td>Single-vessel vs. multivessel disease</td>
<td>3.07</td>
<td>2.87–3.28</td>
</tr>
<tr>
<td>CTO location</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAD vs. RCA</td>
<td>1.58</td>
<td>1.46–1.70</td>
</tr>
<tr>
<td>Operator volume</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low vs. intermediate</td>
<td>0.59</td>
<td>0.54–0.65</td>
</tr>
<tr>
<td>Low vs. high</td>
<td>0.50</td>
<td>0.46–0.55</td>
</tr>
<tr>
<td>Intermediate vs. high</td>
<td>0.85</td>
<td>0.79–0.91</td>
</tr>
</tbody>
</table>

CI = confidence interval; EF = ejection fraction; LAD = left anterior descending; MI = myocardial infarction; RCA = right coronary artery; other abbreviations as in Table 1.
the potential for loss of collaterals; and 3) economic disincentives, a problem unique to U.S. operators.

**Wire-crossing difficulties.** Substantial intellectual and financial resources have been invested in the effort to overcome the difficulty in crossing CTOs with a wire. Technology such as specially designed wires (23) and techniques such as parallel wires, retrograde approaches (24,25), and the subintimal tracking and re-entry technique, among others (26), have been described and demonstrated in a multitude of educational forums. A variety of devices have been developed in an effort to overcome wire-crossing difficulties (27–31). These are largely used as niche devices and will not be extensively reviewed here.

Beginning in 1994, wire design improvements were made and later resulted in better crossing success with antegrade techniques at select centers (32). These wire design improvements included a central core with an outer coil that improved torque responsiveness, tapering of the wire tip from 0.014 to 0.009 inches, the addition of hydrophilic polymer coatings, plastic jackets, and variable tip stiffness. Some of these dedicated CTO wires, which vary in stiffness from floppy (0.5 g) to extremely stiff (12 g), are now available in the U.S. (Table 3).

**Complications associated with CTO angioplasty.** The overall risk of CTO-PCI has been examined in several studies. Compared with a matched cohort of patients undergoing non–CTO-PCI (N = 2,007), we found that those undergoing CTO-PCI (N = 2,007) had similar in-hospital major adverse cardiac event rates, including death (1.3% vs. 0.8%, p = 0.13), Q-wave MI (0.5% vs. 0.6%, p = 0.67), urgent coronary artery bypass graft surgery (0.7% vs. 1.1%, p = 0.25), and combined major adverse cardiac events (3.8% vs. 3.7%, p = 0.90). The occurrence of dissection was more frequent in the CTO group (17.8% vs. 13.3%, p < 0.008), but in this study stenting was performed in only 7% of cases (5). Despite these data, controversy remains surrounding risks that may be uniquely prevalent in CTO-PCI. These risks include coronary perforation, contrast nephropathy, radiation exposure, and collateral loss.

Coronary perforation may be more likely to occur in CTO than in subtotally occluded vessels. Among the cohort of 4,828 patients who underwent CTO-PCI from the NCDR version 3.04, the perforation rate for CTO-PCI was 0.9%. The perforation rate among an unselected cohort of patients undergoing PCI was 0.2% (33). Perforation of the coronary artery has several potential ramifications including intramyocardial hematoma, fistula formation into a cardiac chamber, coronary vein, or a great vessel, limited pericardial hematoma, and cardiac tamponade. Despite relatively high perforation rates compared with non–CTO-PCI perforation rates, in-hospital mortality in the NCDR group was only 0.7%. This compares favorably with mortality rates observed in a contemporary PCI registry, where in-hospital mortality ranged between 0.1% and 3.0% and was related to left ventricular function (34).

Because of the increased potential for perforation, glycoprotein IIb/IIIa inhibitors and direct thrombin inhibitors that have no antidote should not be used when attempting CTO-PCI until a wire is safely delivered to the true lumen of the distal vessel beyond the CTO. The utility of bailout glycoprotein IIb/IIIa inhibition in this setting is unproven. Additionally, we recommend the use of unfractionated heparin, which is immediately reversible upon identification of perforation. Finally, to avoid distal wire perforation, softer-tipped hydrophobic wires should be exchanged for the stiffer hydrophilic CTO wires as soon as the true lumen of the distal vessel has been reached.

Operators performing CTO-PCI should be experienced with a variety of tools needed to deal with coronary

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Wire</th>
<th>Tip Stiffness (g)</th>
<th>Shaft and Tip Diameter (inches)</th>
<th>Hydrophilicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asahi/Abbott</td>
<td>Whisper</td>
<td>1</td>
<td>0.014</td>
<td>Yes</td>
</tr>
<tr>
<td>Medium</td>
<td>3</td>
<td>0.014</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Fielder</td>
<td>1</td>
<td>0.014</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Fielder FC</td>
<td>1</td>
<td>0.014</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Fielder XT</td>
<td>1</td>
<td>0.014</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Miracle Bros.</td>
<td>3, 4, 5, 6, 12</td>
<td>0.014</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Confinanza</td>
<td>9, 12</td>
<td>0.014-0.009</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Confinanza Pro</td>
<td>9, 12</td>
<td>0.014-0.009</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Pilot 50, 150, 200</td>
<td>1.6, 3, 4.5</td>
<td>0.014</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Medtronic</td>
<td>Persuader 3, 6</td>
<td>0.014</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Persuader 9</td>
<td>9</td>
<td>0.014-0.009</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Boston Scientific</td>
<td>Choice PT 2</td>
<td>0.014</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>PT Graphix</td>
<td>3–4</td>
<td>0.014</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Cordis</td>
<td>Shinobi 2</td>
<td>0.014</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Shinobi Plus</td>
<td>4</td>
<td>0.014</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviation as in Table 2.
perfusion. When a wire perforation occurs in smaller distal branches, the branch can be occluded with wire coils, microspheres, a small piece of thrombus, or a small piece of the patient’s subcutaneous fat injected through an end-hole catheter. Similarly, if a wire perforation has occurred in the proximal vessel or within the CTO, the proximal vessel can simply be reoccluded with these materials. A perforation created by a wire exit within the occluded segment can often be remedied by prolonged balloon inflation and conventional stenting. If that fails, a covered stent can be used to seal the perforation (33) or surgical correction can be performed by oversewing the vessel and bypassing the CTO.

The risk of contrast nephropathy is related to contrast volume. Compared with PCI of subtotal stenoses, CTO-PCI is associated with greater contrast volume use. Despite this, we did not find an increased risk of renal failure with CTO-PCI versus PCI of subtotal stenoses in matched patients (5). This discrepancy may reflect patient selection or better use of renal protective interventions in patients with CTO. In fact, renal insufficiency, defined as serum creatinine >2.0 mg/dl, was a strong predictor of deferral of CTO-PCI in the NCDR registry version 3.04 (odds ratio of attempted CTO-PCI: 0.51, 95% CI: 0.42 to 0.64; p < 0.001). Aggressive measures to prevent contrast nephropathy should be employed in high-risk patients.

The risk of radiation injury is related to the dose of radiation during PCI. Procedure and fluoroscopy times are higher for CTO than non–CTO-PCI. Suzuki et al. (35) found that mean fluoroscopy time for CTO-PCI among 75 patients was 45 ± 25 min and the maximum entrance skin dose was 3.2 ± 2.1 Gy. These numbers varied widely between institutions, suggesting that standardized interventions to limit radiation exposure should be considered (36). Operators should attempt to minimize radiation exposure to patients and catheterization staff. This can be accomplished by careful procedure planning, collimation, fluoroscopy at 15 rather than 30 frames/s, frequent movement of the image intensifier angle, maximizing the distance from the radiation source, maximizing imaging in the right anterior oblique views, and accessory lead shielding. Even though it is an imprecise measure of total radiation exposure, fluoroscopy time should be tracked throughout the procedure. Fluoroscopy times exceeding 60 min should be avoided. We recommend that patients exposed to fluoroscopy times >60 min or total dose over 5 Gy receive consultation from a dermatologist or radiation oncologist familiar with the management of radiation dermatitis.

Collateral function in patients with CTO has been extensively studied by Werner and colleagues (37–39). They elegantly demonstrated collateral functional loss by identifying a 50% reduction in mean peak recruitable collateral flow immediately after CTO-PCI (37). In subsequent studies, they demonstrated that only 18% of patients maintain recruitable collateral function adequate to prevent ischemia in the event of an acute reocclusion (stent thrombosis or subsequent acute MI involving the previously dilated CTO vessel), whereas patients with chronic reocclusion (restenosis) had sufficient collateral redevelopment to maintain myocardial viability (38).

The importance of collateral loss, however, may be upstaged by the observation that only 7% of patients had collateral flow reserve sufficient to prevent stress-induced ischemia, and as many as 33% of patients have physiologic evidence of coronary steal (39). These limitations of collateral function lead Werner et al. (37–39) to conclude that even in patients with “well-developed” collaterals, anti-ischemic benefit may be derived from CTO-PCI.

**Economic disincentives to CTO-PCI.** The CTO-PCI procedure is labor- and resource-intensive. Unpublished data from our institution show that the typical CTO-PCI requires twice the procedure (81 min vs. 44 min) and fluoroscopy (40 min vs. 17 min) time as non–CTO-PCI. The average balloon and stent utilization is 2.4 and 1.9 per CTO case compared with 1.5 and 1.7 per non–CTO case, respectively. Given the benefits of CTO-PCI, U.S. payers should reimburse operators and institutions committed to CTO-PCI at a level commensurate with the degree of difficulty, the amount of time, and resources required relative to non–CTO-PCI.

**CTO-PCI Techniques**

Recent advances in CTO-PCI techniques that have broadened PCI indications and improved success rates can be categorized into antegrade and retrograde techniques.

It is also generally agreed by CTO experts that every case of CTO-PCI where contralateral collaterals exist should be done with bilateral injections to allow for simultaneous antegrade and retrograde filling of the target vessel (40).

**Antegrade techniques.** Many experts recommend the technique of using wires of graduated tip stiffness for those learning CTO-PCI techniques (41). For those CTOs selected for an antegrade approach, the operator should begin with a soft tipped, tapered hydrophilic wire (Fielder XT, Abbott Vascular, Inc., Abbott Park, Illinois) in an effort to traverse the CTO through microchannels. The crossing of a CTO through microchannels can be facilitated by contrast injection into the proximal cap through the end of a balloon or microcatheter (42). If penetration of the proximal cap or access through a microchannel is unsuccessful, progressive wire tip stiffness (3-, 6-, and 9-g wires) should be tried. If these fail, a tapered, hydrophilic 9- or 12-g wire should be used. It is noteworthy that the wire tip “stiffness” is related to the distance the tip extends beyond the end hole of the balloon or catheter. A 3-g wire can perform similar to 12-g wire if it is used <5 mm from the end hole of a balloon. A 12-g wire will perform with resistance of 30 to 40 g when it is used within 5 mm of the end hole of a balloon or catheter. No consensus exists over the best method for an initial antegrade attempt. We prefer the graduated approach just outlined for beginning CTO operators.
and recommend that only after significant experience (50 simple CTOs) (44) with graduated wires should operators skip to or start with stiffer wires.

If any of the above mentioned wires is inadvertently advanced into a subintimal space, it should be left in place and a second wire of the same caliber and stiffness should be used. It is recommended that a slightly different tip angle be used for this second wire. This approach is called the “parallel wire technique” (44). When the second wire enters a subintimal space, the first wire is pulled back and an attempt is made to advance this wire into the true lumen. This maneuver is known as the “see-saw wire” technique. On occasion, a third wire may be used to penetrate the cap of the CTO between 2 other wires. It is important to evaluate the course of the subintimal wire in orthogonal views before advancing a second wire.

Operators at the Kurashiki Central Hospital in Kurashiki, Japan, have demonstrated their ability to improve wire-crossing success along a continuum of time (from 62% to 85%) when these techniques were adopted at their center (32).

For operators learning CTO-PCI, these antegrade techniques using a stepwise wire approach should be predominantly used. Although there are a host of CTO niche devices available (28,45), our bias is toward mastering these foundational antegrade wire techniques first.

**Retrograde techniques.** Collaterals channels can be used in a retrograde approach to CTO-PCI. Collaterals can take a septal, atrial, or epicardial course. The ideal channels take a septal course to the recipient vessel, are straight, and have a visible connection on routine nonselective coronary angiography. Even though angiographic evidence of communicating collaterals exists in approximately 50% of cases, many of these will not provide access to the distal CTO vessel. Conversely, many angiographically invisible CTO channels exist and can be unmasked only by selective tip injections through an end-hole catheter or simple probing of proximal septal channels with a soft hydrophilic wire.

Operators learning the retrograde approach should perform selective tip injections of candidate collaterals using end-hole catheters such as the Transit (2.5- and 2.1-F, Cordis Corp., Warren, New Jersey), Excelsior (2.0-F, Boston Scientific, Natick, Massachusetts), Prowler (1.7-, 1.9-, and 2.3-F, Cordis Corp.), or Finecross (1.8-F, Terumo Medical Corp., Somerset, New Jersey) or use the recently approved Corsair channel dilator (Asahi Intecc), recently approved by the Food and Drug Administration, will largely supplant the need to dilate septal collateral channels and perform retrograde dilation of CTO lesions.

When retrograde wire crossing of the CTO into the true lumen is not possible, alternatives include the kissing wire, CART, and reverse CART techniques. Kissing wire technique is executed by penetrating the proximal cap with 1 wire via the antegrade guide and penetrating the distal cap with another wire via the retrograde guide. The 2 wires meet in the middle of the lesion, and the antegrade wire is then advanced along the path of the retrograde wire or vice versa to complete lesion crossing.

When the retrograde wire passes into the subintimal space, the CART technique can be employed. A balloon is inflated in the retrograde subintimal space, creating a dissection. The antegrade wire is then used to reenter the true lumen, often with intravascular ultrasound guidance. Variations of this technique (the reverse CART) have also been employed.

**Selecting the initial approach to CTO-PCI.** No consensus exists for selecting an initial approach to a CTO (antegrade vs. retrograde). The most common reason to use retrograde techniques among experienced CTO operators is failure to succeed using the antegrade approach (65%). If failure with the antegrade approach is imminent and fluoroscopy time is <30 min, the change can be made ad hoc. In the event that greater time has been used, the patient should be brought back for a staged attempt at least 48 h after the first attempt. Certain subsets of patients, including those with long lesions (>20 mm), ostial occlusions, extreme tortuosity, severe calcification,
Conclusions

Training CTO-PCI Operators

Training in CTO-PCI requires a substantial commitment of time and resources by operators and institutions. One approach to training less experienced operators in the advanced techniques of CTO-PCI is to dedicate a day to perform CTO-PCI and have more experienced operators directly mentor less experienced operators during cases. Such a “CTO-Day” program can be enhanced by a visit from experts in the retrograde techniques. This type of continuously mentored practice improvement has been very effective at our institution. The commitment of time and resources for a CTO-Day program may not be possible at some institutions, and the alternative of visiting American, European, or Japanese CTO centers or CTO club meetings for focused training is an option (22). Training volume recommendations have been outlined by the European CTO club (43), and we concur with those recommendations, although the volume requirements are somewhat arbitrary. It is appropriate that operators who do not wish to take on these difficult and time-consuming procedures refer difficult cases to colleagues at centers where these procedures are performed on a routine basis.

When non-CTO operators wish to embark on CTO-PCI training, they should select CTOs with favorable characteristics followed by more difficult lesions according to the recommendations of the European CTO club (43). Favorable CTO characteristics include those described by Dong et al. (46), such as a tapered proximal CTO cap, CTO length of <15 mm, proximal vessel angulation of <45°, and single versus multiple total occlusions within the target vessel. Only after achieving volumes recommended by the European CTO club (50 simple CTOs) should CTO trainees embark on learning the more difficult techniques and using niche devices in carefully selected cases, preferably with the direct supervision of an experienced operator. It is typical for success rates to again decline as operators take on more difficult procedures. To maintain expertise, the European CTO club recommends performance of at least 50 CTO-PCIs per year per operator. Maintaining these volumes requires hospitals and groups to limit CTO-PCI procedures to approximately 1 CTO operator for every 500 PCIs performed.

Conclusions

In summary, at experienced centers, CTO-PCI is safe, results in symptom relief, improvement in left ventricular function, and perhaps improved long-term survival. Disparity in CTO-PCI attempt rates between low- and high-volume interventionalists suggests that similar patients do not have equal access to therapeutic strategies due to system-based barriers. These barriers could be overcome through formalization of training in advanced techniques, encouragement of referral, standardization of practice patterns, and reimbursement commensurate with the time and resources needed to effectively treat these complex patients percutaneously.

Acknowledgments

The authors wish to acknowledge the American College of Cardiology’s NCDR for providing much of the data discussed in this manuscript. They also wish to thank Joseph Murphy for editorial expertise.

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REFERENCES


Key Words: coronary artery disease □ chronic total occlusion □ angioplasty.

APPENDIX

For the steps involved in performing true retrograde approach, please see the online version of this article.
**Chronic Total Occlusion Angioplasty in the United States**
J. Aaron Grantham, Steven P. Marso, John Spertus, John House, David R. Holmes, Jr, and Barry D. Rutherford

*J. Am. Coll. Cardiol. Intv.* 2009;2;479-486
doi:10.1016/j.jcin.2009.02.008

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