JACC: CARDIOVASCULAR INTERVENTIONS VOL. 2, NO. 9, 2009

ISSN 1936-8798/09/$36.00
PUBLISHED BY ELSEVIER INC. DOI: 10.1016/j.jcin.2009.05.022

Retrograde Techniques and the Impact of Operator Volume on Percutaneous Intervention for Coronary Chronic Total Occlusions

An Early U.S. Experience

Craig A. Thompson, MD, MMSc,* John E. Jayne, MD,† John F. Robb, MD,† Bruce J. Friedman, MD,† Aaron V. Kaplan, MD,† Bruce D. Hettleman, MD,† Nathaniel W. Niles, MD,† William L. Lombardi, MD‡

New Haven, Connecticut; Lebanon, New Hampshire; and Bellingham, Washington

Objectives Our purpose was to determine if "Japanese style" technical strategies can be successfully applied in the U.S. practice environment and to better understand the learning curve for chronic total occlusion (CTO) percutaneous coronary intervention (PCI).

Background Procedural technical success remains the major limiting factor for CTO PCI, and has been unchanged over time.

Methods Demographic, procedural, and outcome data were collected on 636 consecutive patients between January 2005 and March 2008 having CTO PCI (514 antegrade, 122 retrograde attempts) at 2 U.S. medical centers. Operators were divided into 2 groups: higher CTO volume, retrograde operators (ROs) (>75 total CTO PCI cases and >20 retrograde attempts during the study period) and lower CTO volume, nonretrograde operators (NROs) to evaluate the impact of CTO-specific operator case volume and retrograde techniques on procedural outcomes.

Results Two operators met the criteria for RO category and 10 were NRO. ROs performed 395 CTO PCI cases (mean total CTO case experience = 197.5, 60 retrograde) and NROs performed 241 CTO PCI cases (mean total CTO case experience = 24.1, <1 retrograde) during the observed timeframe. The overall technical success was 58.9% for NROs and 75.2% for ROs ($p < 0.0001$). The technical success rate of NROs did not change, but the technical success for the ROs increased to 90% over time ($p < 0.0001$ for trend, 94.4% for retrograde and 85.7% for antegrade approaches). Observed major adverse events were similar between ROs and NROs.

Conclusions Complex antegrade and retrograde "Japanese style" PCI approaches can be applied in the U.S. practice environment with high technical success and low adverse event rates. Higher CTO-specific operator case volume is associated with improved technical success rates. (J Am Coll Cardiol Intv 2009;2:834–42) © 2009 by the American College of Cardiology Foundation

From the *Yale University School of Medicine, New Haven, Connecticut; †Dartmouth Hitchcock Medical Center, Dartmouth Medical School, Lebanon, New Hampshire; and the ‡North Cascade Cardiology–St. Joseph's Hospital, Bellingham, Washington. Dr. Thompson is on the medical advisory board of Abbott Vascular and Infraredx, and is a consultant for Medtronic and Bridgepoint Medical. Dr. Lombardi is on the medical advisory board of Abbott Vascular, and is a consultant for Medtronic and Bridgepoint Medical. Dr. Kaplan is the founder of Tryton Medical.

Manuscript received March 6, 2009; revised manuscript received May 6, 2009, accepted May 15, 2009.

Coronary chronic total occlusions (CTOs) are identified frequently during coronary angiography. Successful percutaneous coronary intervention (PCI) of CTO is associated with improved cardiac symptoms, improved survival, reduced referral for coronary bypass surgery (CABG), and reduced major adverse cardiac events compared with unsuccessful PCI (1–5). Drug-eluting stents appear to have improved long-term durability in CTO (6–11). However, acute technical success rates for CTO recanalization are low compared with nonocclusive stenoses, and have not improved dramatically over time (1–5).

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While novel technologies targeting coronary CTO hold promise, recent improvements in CTO PCI technical success rates appear to be more attributable to evolutionary improvement of conventional PCI equipment (e.g., guidewires, support catheters) coupled with the introduction of novel techniques such as the retrograde approach. These technique-driven advances have largely been attributed to several advanced operators from Japan (12–17). However, the potential for translation of these techniques to a Western patient population and practice environment remains unclear. The purpose of this report is to describe an early U.S. retrograde CTO PCI experience and to evaluate the impact of CTO-specific operator case volume on acute procedural outcomes.

Methods

Study population. This present report is an observational study, between January 2005 and March 2008, in which 636 patients with coronary CTO had PCI attempted at 2 high-volume medical centers (1 academic medical center, 1 private practice). Patient accrual and follow-up occurred during this timeframe, which was divided into time increments (early 2005 [January to June 2005], late 2005 [July to December 2005], early 2006 [January 2006 to June 2006], late 2006 [July 2006 to December 2006], early 2007 [January 2007 to June 2007], and late 2007/early 2008 [July 2007 to February 2008] to assess temporal changes in practice patterns and outcomes over time. CTO was defined as 100% coronary arterial occlusion with Thrombolysis In Myocardial Infarction (TIMI) antegrade flow grade 0, with angiographically proven or estimated duration >3 months based on perfusion scanning or symptoms. Twelve operators performed CTO PCI at these centers during this time period. We divided the operators into 2 groups to better understand the effect of retrograde technique and CTO-specific experience (antegrade and retrograde) on learning curve and outcomes: retrograde operators (ROs) (>75 total CTO PCI cases and >20 retrograde attempts during this time period) and nonretrograde operators (NROs). The RO and NRO groups are represented by a combination of this report's authors. Baseline patient characteristics, procedural details and techniques, and in-hospital outcomes were recorded. The primary observation reported was procedural technical success (<50% residual stenosis at the target CTO lesion with TIMI anterograde flow grade 3). Secondary observations included complications (death, myocardial infarction, major and minor coronary perforation), technical success rate by "intended initial strategy" as well as "actual treatment strategy," and temporal trends in success and treatment patterns.

Chronic renal failure was defined as baseline creatinine >2 mg/dl, and congestive heart failure was defined as history of the clinical heart failure syndrome requiring therapy or hospital admission or left ventricular ejection fraction ≤35% (even absent symptoms). Significant perforation was defined as any perforation leading to hemodynamic instability and/or requiring pericardiocentesis, stent graft, or embolic or comparable interventional therapy for repair. Myocardial infarction was defined as >3× upper limit of normal creatine phosphokinase release with associated positive creatine kinase-MB fraction or positive troponin T, in absence of escalating creatine phosphokinase before PCI; major adverse cardiac events was a composite of death, myocardial infarction, and significant perforation.

Statistical analysis. Categorical variables were compared with continuous variables using unpaired *t* tests or analysis of variance. Multiple comparisons between continuous variables were performed by multiple or stepwise linear regression modeling, or by logistic regression or analysis of covariance/multiple analysis of variance when appropriate for categorical versus continuous variables. Correlation was performed by Spearman and Pearson methods. All statistical work was performed using JMP 7 software (SAS Institute, Inc., Cary, North Carolina). This observational analysis was approved by the local institutional review board.

Retrograde technical strategies. All techniques described hereafter involved placement of a guidewire retrograde through collateral vessels to gain a position within the CTO target vessel distal to the occlusive lesion. These collaterals often were from the contralateral coronary artery, and therefore dual arterial access and dual, bilateral guide catheters were usually required. Shortened guiding catheters (85 to 90 cm) were used for the retrograde guide catheter (in virtually all cases) to allow appropriate working length given the greater intracoronary distances traveled. Many of these guides were purchased from catheter manufacturers with pre-specified custom lengths and shapes. Others were "custom designed" by the operators by cutting guides with desired tip shape near the proximal hub and reconnecting the ends with a piece of introducer sheath

Abbreviations and Acronyms

CABG = coronary bypass surgery

CART = controlled antegrade and retrograde tracking

CTO = chronic total occlusion

NRO = nonretrograde operator

PCI = percutaneous coronary intervention

PTCA = percutaneous transluminal coronary angioplasty

RO = retrograde operator

TIMI = Thrombolysis In Myocardial Infarction

(1-F size smaller outer diameter) used as an interposition conduit. Longer femoral sheaths (35 cm) were used at operator discretion to increase passive guide support and minimize iliac tortuosity and its impact on fine wire manipulation. Sidehole guide catheters were common for the right coronary artery guide and used on the left coronary artery when small caliber or diseased left main was present. Traversing collaterals to place a wire or other equipment in the distal CTO vessel lumen comprised an essential component of these techniques, and contributed significantly to the learning curve.

KISSING WIRE TECHNIQUES. In this method, the retrograde wire was placed in the true lumen distal to the CTO to serve as an unambiguous marker of true lumen location for antegrade wiring, which could allow for reduced contrast utilization (Fig. 1). The retrograde wire was then advanced into the CTO and, subsequently, both antegrade and retrograde wires could be manipulated within the lesion to touch one another (true "kissing wire" technique). When the wires contacted, the operator could often establish the path between the proximal and distal true lumens by further advancement of the anterograde wire along the course of the retrograde wire. This greatly improved orientation and reduced contrast exposure for the patient by reductions in the need to continually attempt to fill the distal bed.

PRIMARY RETROGRADE WIRE CROSSING. The retrograde wire was used to completely cross the CTO, being advanced upstream from the distal true lumen, through the CTO, and into the proximal true lumen. This successfully passed retrograde wire was then used as a rail for percutaneous transluminal coronary angioplasty (PTCA) of the lesion (Fig. 2). This could be accomplished in several ways. Often, the wire that crossed the retrograde collateral channel could primarily cross the CTO retrograde. This wire was then advanced through the coronary ostium well into the aorta, or optimally, into the antegrade guide and "anchored" with an angioplasty balloon inflated in the antegrade guide (to fix this wire in position). If the collateral was a septal artery, the entire septal was dilated with a 1.5-mm PTCA balloon at low (1 to 2 atm) pressures. Epicardial and atrial collaterals were NOT dilated, but occasionally were large enough to allow passage of PTCA balloons easily and without excessive resistance. Retrograde PTCA of

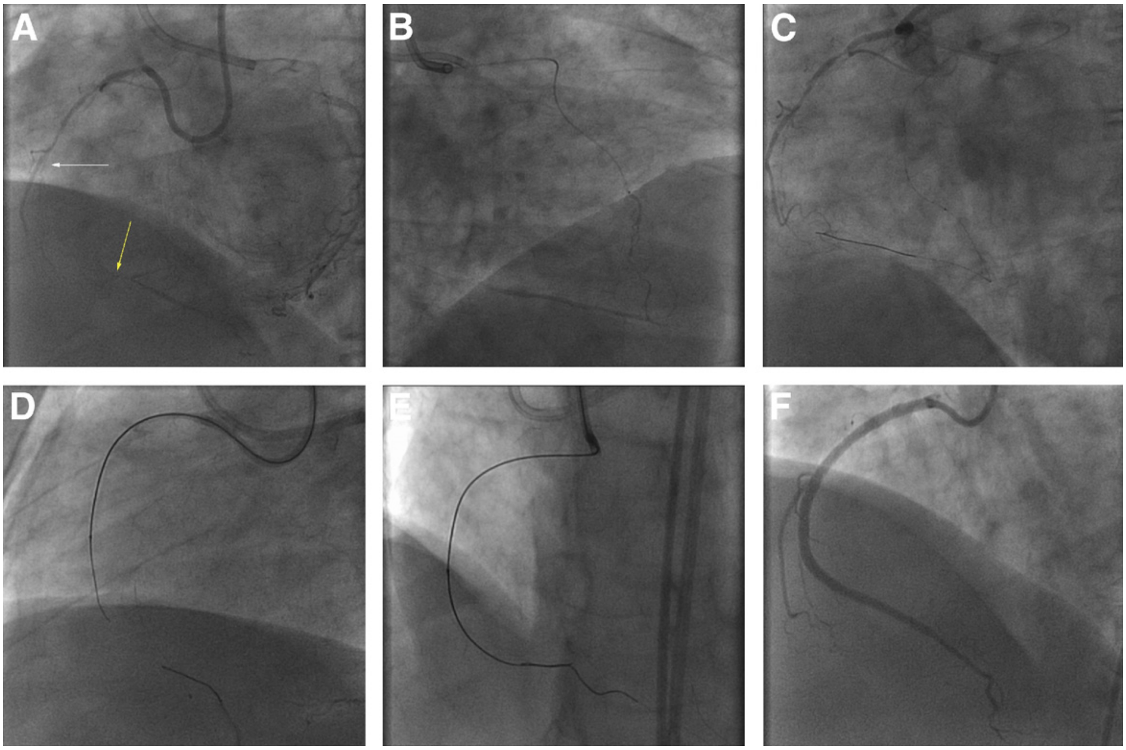

Figure 1. Retrograde and Antegrade Kissing Wire Technique

This long segment right coronary artery chronic total occlusion had been unsuccessfully attempted previously (**white arrow**, proximal cap; **yellow arrow**, distal cap) **(A)**. A target septal artery was identified from surface coronary angiogram, and supraselective septal angiography was performed through microcatheter, demonstrating a continuous collateral to right coronary posterior descending artery **(B)**. A Fielder wire (Asahi-Intec) was advanced carefully from the septal, through the right posterior descending artery, and into the distal right coronary artery **(C)**. This served as an unambiguous marker and target for advancement of anterograde wire **(D)**, and both wires were manipulated until apparent contact was achieved in multiple projections **(E)**. After multiple drug-eluting stents, good angiographic success was achieved **(F)**.

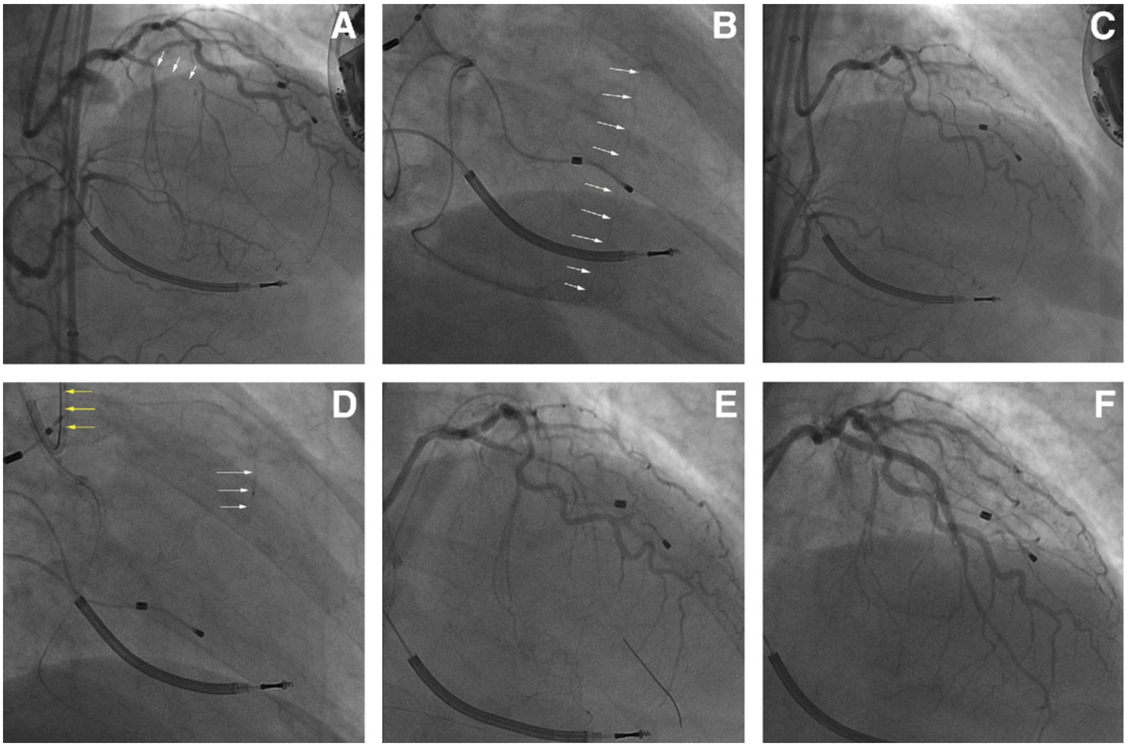

Figure 2. Primary Retrograde Wire Crossing

This patient with left anterior descending chronic total occlusion was a reattempt after antegrade parallel wire failure (chronic total occlusion, **white arrows**) **(A)**. Selective septal injection was performed using microcatheter and identified continuous collateral **(white arrows)** from right posterior descending artery to left anterior descending **(B)**. A Fielder fine control wire (Asahi-Intec) was advanced through the septal collateral and engaged in the distal chronic total occlusion cap **(C)**. This wire was able to negotiate the entire length of the chronic total occlusion and was advanced into the antegrade guide catheter. This wire was anchored with the "trapping balloon" technique using inflation of a 2.5-mm percutaneous transluminal coronary angioplasty balloon in the anterograde guide to fix the wire **(yellow arrows, D)**, and septal dilation was performed with a 1.5-mm balloon at low pressures **(D)**. The chronic total occlusion was subsequently dilated with this 1.5-mm balloon over the retrograde wire. An antegrade wire was then easily advanced to the distal left anterior descending **(E)**, and after 2 drug-eluting stents and kissing percutaneous transluminal coronary angioplasty at 2 left anterior descending-diagonal bifurcations, good angiographic result was obtained **(F)**.

the CTO was then performed to pilot a channel in the CTO, followed by conventional antegrade PCI.

Occasionally, the floppy wire used to traverse the collaterals could not penetrate the CTO lesion retrograde. In this case, if a PTCA balloon could be delivered through the collaterals to the distal artery, it was inflated as a distal "anchor" and used to exchange for advanced wires for retrograde CTO penetration and crossing (e.g., Miracle bros 3, 6, 12 g, Confianza pro 9, 12 g, all manufactured by Asahi-Intec, Nagoya, Japan).

One additional technique utilizing retrograde wire crossing involved externalization of the retrograde guidewire via the antegrade guide catheter after the wire traversed the collaterals and CTO lesion, and exited the ostium of the target coronary. When this was accomplished, the operator could control both ends of a single wire traversing the vasculature including the CTO. This required either primary lesion crossing with a 300-cm wire or use of a microcatheter/balloon to cross the lesion traveling on a shorter retrograde wire, which was then exchanged for a long wire such as the 300 cm (Fielder, Abbott Vascular, Santa Clara, California). Once externalized, the wire could be used antegrade for PTCA or exchanged using a microcatheter system. Wire externalization was a particularly important technique when retrograde wiring was possible but retrograde balloon placement could not be achieved.

DISSECTION TECHNIQUES. Controlled antegrade and retrograde tracking (CART technique) has been a major advance in complex coronary CTO PCI and previously described (14) (Fig. 3). Briefly, antegrade and retrograde wires were advanced into the CTO and false lumens (when the true lumen beyond the CTO lesion could not be accessed). A retrograde balloon (after entire septal dilation or in large epicardial collateral) was advanced and dilated in the distal CTO cap, thus expanding the subadventitial/sublesional/subintimal space. The antegrade wire (Confianza 9, 12 g, Miracle 12 g, Fielder, Asahi-Intec) was directed toward the retrograde balloon as it was deflated. The retrograde balloon could serve as an accurate target and as a space occupier in the false lumen. Once the antegrade wire entered this space, it could be further advanced back into the

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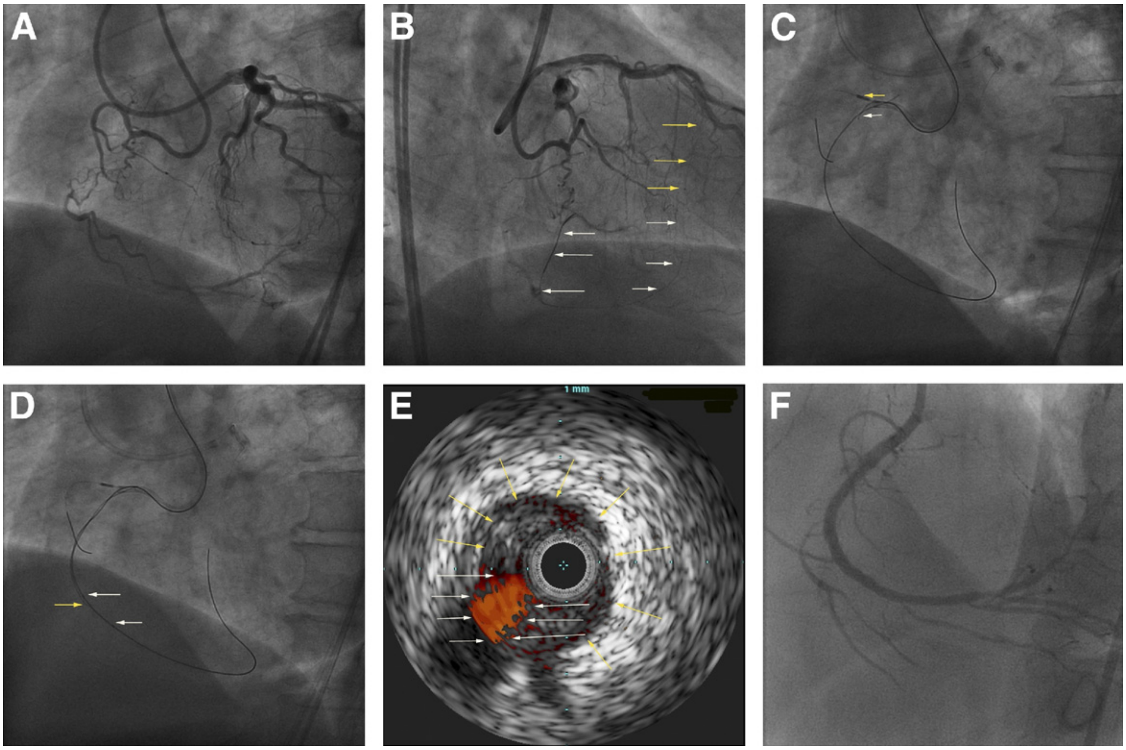

Figure 3. CART Technique

This patient had chronic total occlusion of the right coronary artery with bridging collaterals, left anterior descending artery to right coronary artery septal collaterals, and proximal and distal caps located at side branches **(A)**. A 0.014-inch Fielder fine control wire (Asahi-Intec) was placed from the left anterior descending artery to right coronary artery posterior descending artery into an acute marginal branch **(white arrows)** using microcatheter support **(yellow arrows)**, septal dilation performed with a 1.5-mm balloon at 1 atm, and a 2.5 × 15 mm Voyager (Abbott Vascular) balloon placed in the mid/distal right coronary artery. **(B)** After inability to penetrate the distal cap retrograde with multiple wires, a Confianza pro 9 g wire (Asahi-Intec) was delivered retrograde into the proximal right coronary artery subintimal space, as determined by intravascular ultrasound **(yellow arrow)**. An antegrade Confianza pro 12 g wire (Asahi-Intec) was introduced into the proximal chronic total occlusion using intravascular ultrasound guidance **(white arrow, C)**. The retrograde balloon is used to dilate from distal true lumen into distal chronic total occlusion subintimal space. The antegrade wire is directed toward the retrograde balloon, which serves as a marker and space occupier, and the antegrade wire is delivered to distal true lumen **(D)**. In this patient, intravascular ultrasound with color flow (**red color**, chromaflo, Eagle-eye catheter, Volcano Therapeutics, San Diego, California) was performed, and demonstrated the controlled antegrade and retrograde tracking (CART) re-entry site (**white arrows**, false lumen; **yellow arrows**, true lumen) **(E)**. After multiple drug-eluting stent placements, a good angiographic result was achieved **(F)**.

true lumen along the path taken by the retrograde balloon and wire. The controlled dissection was thus used as a bridge to connect proximal and distal true lumens, effectively bypassing the occlusion.

Reverse CART is a variant of CART in which the PTCA balloon was dilated over the antegrade wire and the crossing performed primarily with the retrograde wire. This technique had more limited application during *this study period* because of larger dissections created and relatively poorer control of the retrograde wire.

Results

Baseline characteristics of the RO and NRO groups were balanced except for prior CABG and PCI. In addition, history of prior myocardial infarction was observed more frequently in the NRO group (Table 1).

During the study period, 636 CTO PCI cases were performed at the 2 centers, with 122 retrograde CTO PCI attempts. Of the 12 operators, 2 met the criteria for RO category and 10 were NROs. Three hundred ninety-five CTO PCI cases were performed by the 2 RO operators (mean CTO case experience = 197.5, 60 retrograde) and 241 by the 10 NRO operators (mean CTO case experience 24.1).

The overall technical success during this study period was 58.9% for the NRO group and 75.2% for the RO group ($p < 0.0001$) (Table 2). The RO and NRO groups had similar technical success rates during the early study time period, but the NROs remained similar throughout the study period compared with the RO group that experienced greater technical success over time with ~90% technical success in the most recent time periods (Fig. 4A). During this study period, the RO group had a much greater increase in coronary CTO-specific experience (average of 55 and 60 cases during

Table 1. Baseline Characteristics

	Nonretrograde Operator (n = 241 Cases)	Retrograde Operator (n = 395 Cases)	p Value
Age (yrs)	62.9	65.1	NS
Men (%)	77.2	82.3	NS
Hypertension (%)	70.4	67.8	NS
Hyperlipidemia (%)	79.8	71.3	NS
Diabetes (%)	27.0	30.0	NS
CHF (%)	12.0	15.0	NS
Prior MI (%)	32.0	23.2	0.01
Chronic renal failure (%)	8.3	8.3	NS
Prior PCI (%)	38.2	18.7	0.0001
Prior CABG (%)	12.9	35.5	0.0001
Vessel (%)			
LM	1.2	1.1	
LAD	32.0	22.5	
LCx	30.7	27.3	
RCA	35.7	49.1	0.009

CABG = coronary artery bypass grafting; CHF = congestive heart failure; LAD = left anterior descending coronary artery; LCx = left circumflex artery; LM = left main artery; MI = myocardial infarction; PCI = percutaneous coronary intervention; RCA = right coronary artery.

the most recent 2 study periods) compared with the NRO group who experienced no such acceleration and averaged <6 cases during each study period (Fig. 4B). The RO group performed ~40% of CTO PCI cases using retrograde technique during the most recent time periods. ROs had shorter procedure times and used less contrast than NROs, though fluoroscopy times were similar (Table 2).

In patients in whom the retrograde technique was attempted, retrograde wire advancement to the distal CTO cap through the collateral channel was successful in 81.1% of cases. The retrograde channel used was a septal collateral in 54.9%, an epicardial collateral in 32.8%, septal and epicardial collaterals in 2.5%, and atrial collaterals in 1.6% of cases. A vein graft was used as the retrograde channel in 8.2% of cases. *Successful placement of a retrograde wire through the collateral channel into the target vessel distal to the occlusion, irrespective of final retrograde tech-*

Table 2. CTO PCI Procedural and In-Hospital Outcomes

	Nonretrograde Operator (n = 241 Cases)	Retrograde Operator (n = 395 Cases)	p Value
Procedural success (%)	58.9	75.2	<0.0001
Procedure time (min)	141.1	107.3	<0.0001
Fluoroscopy time (min)	45.0	42.0	NS
Contrast total (cc)	433.5	342.2	<0.0001
Death (%)	0	0	NS
Myocardial infarction (%)	3.32	2.53	NS
Significant perforation (%)	0.83	1.01	NS
MACE (%)	4.15	3.04	NS

CTO = chronic total occlusion; MACE = major adverse cardiac events (death or myocardial infarction or major perforation, reported as mean values); PCI = percutaneous coronary intervention.

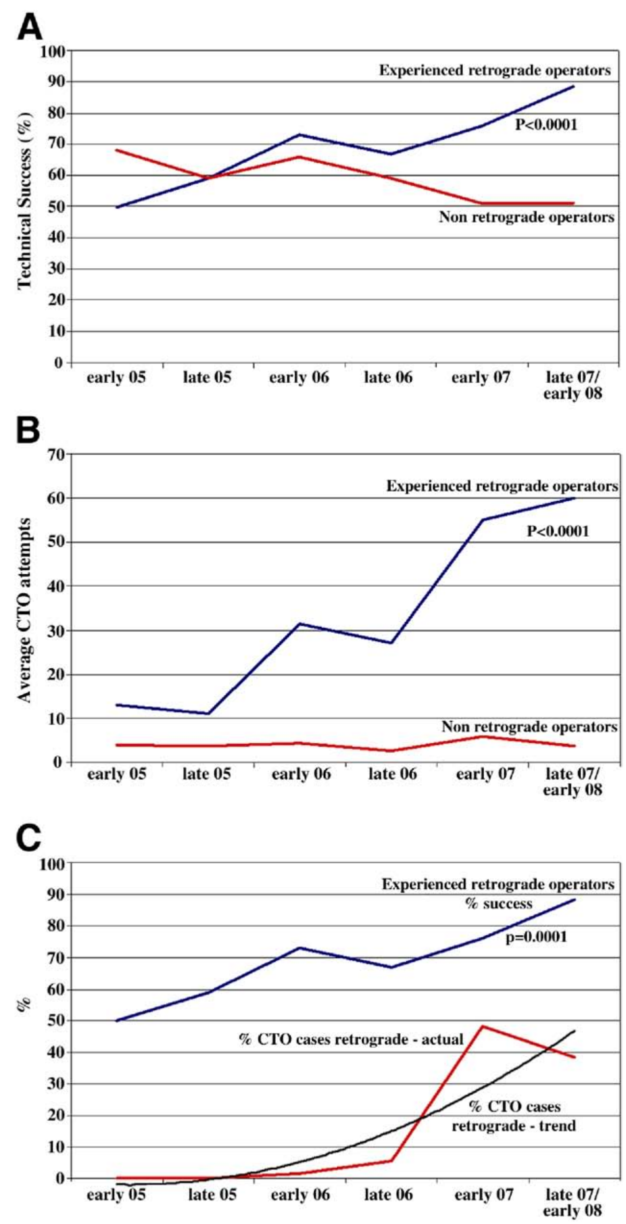

Figure 4. Temporal Trends and Learning Curve for High Volume, Retrograde, Experienced Operators

(A) The operators in the retrograde-experienced, high volume group had statistically significant improvement over time in technical chronic total occlusion (CTO) percutaneous coronary intervention success, approaching 90% in the more recent time period, compared with the nonretrograde experienced, lower volume operator group, which remained statistically similar over time. **(B)** The average attempts in the experienced retrograde operator group accelerated over time to >55 to 60 in the more recent study periods, compared with an unchanged attempt rate <6 per time period in the nonretrograde experienced lower volume group. **(C)** During the most recent study periods, retrograde technique accounted for ~50% of total CTO percutaneous coronary intervention cases for the retrograde experienced, higher volume operators (05, 06, 07, 08 refer to 6-month categories in years 2005, 2006, 2007, and 3 months in 2008).

nique, was a predictor of CTO PCI technical success (86.9% technical success for successfully placed retrograde wire vs. 65.2% success when retrograde wiring was attempted but not successfully placed, p = 0.01). Furthermore, retrograde placement of a large balloon in the distal bed was a powerful predictor of technical success. The technical success rates observed were 90.9% for CART or true retrograde (e.g., large retrograde balloon-based techniques), 82.5% for "kissing wire" strategies, and 70.4% for cases that were converted to antegrade approach from intended but unsuccessful retrograde attempt.

Success for these retrograde techniques improved with RO experience over time (Fig. 5A). The success rates for both retrograde and anterograde significantly improved over time for the RO group (Fig. 5B). The technique in successful retrograde cases was kissing wire in 32%, true retrograde wire crossing in 25%, conversion to antegrade in 19%, CART in 15%, and reverse CART in 9%. A trend is observed in the more recent time periods towards more frequent use of CART and true retrograde wire crossing/PTCA compared with the other techniques.

The overall cited indications for retrograde technique included previous failed antegrade attempt (55%), long lesion (24%), small distal vessel (14%), and ostial occlusion (7%). For the ROs, the indications and threshold for utilizing a retrograde approach changed over time from being dominated by an indication of previous antegrade failure to a strategy of primary approach for cases with high anticipated technical complexity (long lesions, small distal vessel/target, and ostial occlusions), presumably based on iterative learning. In early 2007, 33.9% of retrograde CTO PCI by the RO group (total CTO cases in this time period = 110, total retrograde cases = 53) were performed as a primary strategy for high technical complexity, the remaining (66.1%) retrograde cases being performed for prior antegrade failure. In late 2007/early 2008, 56.9% of retrograde PCI attempts (total CTO cases in this time period = 120, total retrograde cases = 47) were performed as a primary strategy for anticipated high technical complexity, with the remainder (53.1%) being performed in the setting of previous antegrade failure. Procedural characteristics were similar between the previous antegrade failure and high technical complexity indications, including similar procedure time (117.3 min vs. 110.8 min, respectively, p = 0.3), fluoroscopy time (44.3 min vs. 41.5 min, respectively, p = 0.3), contrast total (316.6 ml vs. 354.9 ml, respectively, p = 0.8), stent count (1.33 vs. 2.56, respectively, p = 0.1), and total stented length (56.4 mm vs. 60.2 mm, respectively, p = 0.7).

No significant differences in adverse event rates were seen when analyzing with regard to operator retrograde experience/volume group category (Table 2), or lesion treatment with the antegrade versus retrograde approach. No in-hospital deaths were seen in either the retrograde or antegrade approach group in this time period, and rates of myocardial infarction (3.3% antegrade vs. 0.8% retrograde, p = NS), significant perforation (0.97% antegrade vs. 0.82% retrograde, p = NS), and overall adverse event (death/myocardial infarction/significant perforation 3.8% antegrade vs. 1.64% retrograde, p = NS) were similar for both approaches. As seen in Table 2, the RO group assignment does not appear to increase overall adverse events despite the new technical strategies. We did observe 2 septal artery (instrumented collateral) perforations associated with enzymatic evidence of myocardial infarction, and 1 case of coronary artery to coronary venous fistula (no sequelae). These complications appear unique to the retrograde approach compared with antegrade, but did not require further therapy (embolization, and so on).

After adjustment for differences in baseline characteristics (age, sex, prior myocardial infarction, prior PCI, prior CABG, left anterior descending coronary artery CTO, right coronary artery CTO), a high volume of experience as seen in the RO group was strongly associated with technical success (adjusted

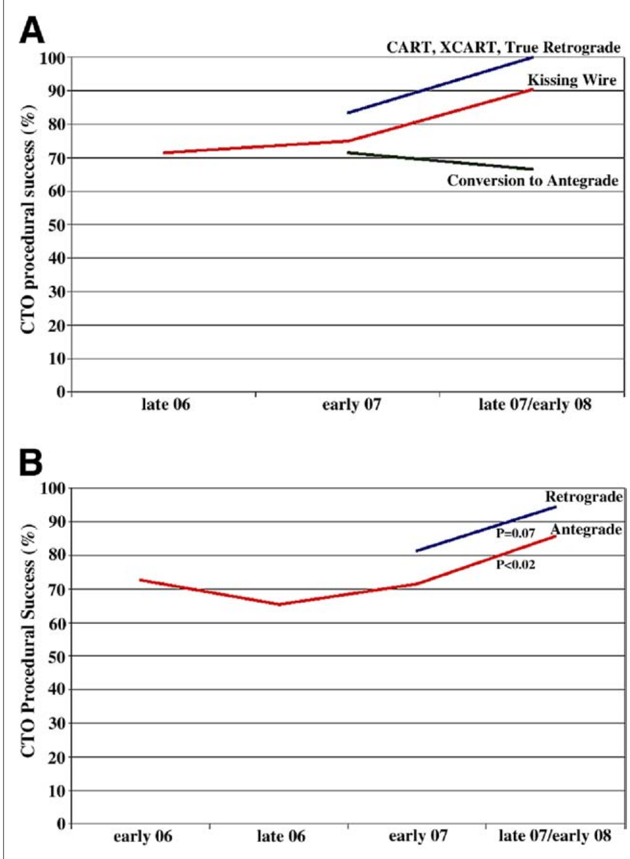

Figure 5. Temporal Success of Antegrade and Retrograde Techniques

(A) (Retrograde operator only) Kissing wire and balloon-based techniques had improved success over time with greater operator experience. **(B)** (Retrograde operator only) Both antegrade- and retrograde-specific chronic total occlusion (CTO) experience seem to inform one another, and success with both approaches improved for the retrograde operators over time (06, 07, 08 refer to 2006, 2007, 2008). CART = controlled antegrade and retrograde tracking; True Retrograde = primary retrograde wire crossing and angioplasty; XCART = reverse controlled antegrade and retrograde tracking.

odds ratio: 2.11, 95% confidence interval: 1.50 to 2.98) (Table 3). When retrograde technique (irrespective of operator classification) is included in this model, retrograde technique is observed to be a predictor of technical success (odds ratio: 2.48, 95% confidence interval: 0.19 to 0.73, p = 0.0001). Prior history of CABG was a negative predictor of success for the overall patient cohort in both models (Table 3).

Discussion

The primary findings of this observational investigation were that CTO experience measured by operator CTO-specific coronary PCI volume, and the adoption of "Japanese style" approaches, are associated with improved technical success rates without compromising patient safety. It is feasible to develop this practice pattern in the U.S. clinical environment.

Coronary CTOs have numerous adverse clinical implications and remain a leading cause for referral from PCI to CABG and for incomplete revascularization. Multiple registry experiences suggest that many patients with CTO do not receive either surgical bypass or percutaneous revascularization for the involved artery territory, despite evidence that suggests lessening of angina, improved regional and global left ventricular function, and potentially improved survival result from successful revascularization of the attributable CTO. We would speculate that among the major reasons for the relatively low attempt rates for CTO PCI are the complexity of the PCI procedure and low technical success rates compared with nonoccluded, stenotic lesions. In heretofore published experiences, technical success rates have not improved dramatically for the majority of operators within the U.S. in recent years (18,19).

Dramatic shifts in technique, largely pioneered in Japan, coupled with refinements in conventional guidewires and other equipment, have set the stage for a new era in PCI of CTOs. Several highly experienced and skilled operators have clearly demonstrated improvements in technical success with these lesions. It was not clear if these experiences could be translated to a U.S. practice environment where the cath lab environment and workflow demands, as well as patient characteristics (body mass index, extent of lesion calcification, applicable collateral anatomy, and so on), may be significantly different. The purpose of this observational analysis was to gain initial insight into the learning curve and potential added value of retrograde CTO PCI within a well-defined practice scope at 2 centers in the U.S.

A learning curve clearly exists for retrograde PCI approach. An "inflection point" in this observational report seemed to occur for the RO group at about 125 coronary CTO cases/operator, in the time frame of this study, where both adoption of retrograde techniques as well as improvements in technical success occurred. The operators in the RO group spent much time at national meetings in didactic sessions dedicated to this topic. *Furthermore, and likely most importantly, the ROs benefited from on-site training and close dialogue with highly experienced ROs in the early cases. Subtle nuances in procedural decision making gained from an experienced retrograde CTO operator in a "real time" case format cannot be underestimated.* In addition, our interpretation of these data is that both retrograde and antegrade technical experience "inform" one another and have provided improved success for both approaches, as evidenced by improvements in success rates in the antegrade CTO PCI approach over time in the RO group as CTO-specific experience grew.

This report may contradict widely held notions about complex CTO PCI in the U.S. The primary finding of this study is that "Japanese style" technical strategies can be transplanted to U.S. clinical practice settings with success rates of ~90+%, both in private and academic practice environments. Concerns that poor workflow and patient- and operator-related variables would detract from this style of practice in the U.S. do not seem justified. Despite the seemingly more complex strategies, overall adverse cardiac events are not seen more frequently with retrograde compared with antegrade approaches or operators. There has been promising adoption of these techniques by select sites in Europe as well (20). We would emphasize that the learning curve for these technique should be a deliberate, stepwise process including proctoring and continuing medical education conferences, with patient safety being the primary concern during skills advancement.

We acknowledge that the data in the RO group was based on a limited number (n = 2) of operators and may not be universally reproduced throughout the U.S. Although this registry experience cannot address the ability to successfully and broadly disseminate these methods in the U.S. practice environment, we do believe this present report supports the feasibility of these approaches for CTO PCI. Based on this reported experience and the positive impact of CTO-specific case volume on technical outcomes, we recommend that CTO PCI be approached as an interventional subspecialty, similar to interventional procedures for structural heart disease and peripheral vascular disease. In this model, local and regional expertise for complex CTO or prior CTO PCI failure referral

Table 3. Crude and Adjusted Multivariate Analysis of Successful CTO PCI

	Crude Odds Ratio	95% CI
Experienced retrograde operators	2.11	1.50–2.98
	Adjusted Odds Ratio	**95% CI**
Experienced retrograde operators	2.38	1.63–3.48
Male sex	0.84	0.53–1.31
Prior MI	0.75	0.50–1.15
Prior PCI	1.16	0.76–1.80
Prior CABG	0.56	0.37–0.84
LAD	1.02	0.65–1.63
RCA	1.10	0.73–1.66

CI = confidence interval; CTO = chronic total occlusion; other abbreviations as in Table 1.

can be established. It would be reasonable, then, to envision a system of tiered CTO PCI practice that would engage more of the interventional community in the process and extend care to a larger group of patients with chronic total coronary occlusion. Additional development of technologies and techniques for this challenging subset of PCI lesions could potentially extend this level of care further.

This present report was not designed to specifically identify "traditional" risk factors for CTO PCI failure, and it is conceivable that a disparity in the angiographic factors associated with success and failure accounted for the technical success imbalance between the groups. We do not believe this is likely the case due to referral bias for complex disease to the RO group, the higher percentage of prior antegrade CTO PCI failures attempted in the RO group, and a higher percentage of patients with prior CABG in the RO group (CABG identified in this study as negative independent predictor for success). We surmise that is it more likely that more complex disease was treated by the RO group rather than less. In addition, CTO-specific technologies did not markedly change during the time frame of this study, and are unlikely to account for the findings of improvement in technical success for the RO group.

Conclusions

In summary, we conclude that high technical success rates of ~90% can be achieved in the U.S. practice environment utilizing "Japanese style" anterograde and importantly retrograde approaches for CTO PCI. We have seen a clear added value of high operator CTO-specific case volume and the addition of retrograde technique for CTO PCI. Adoption of a high volume CTO practice pattern coupled with Japanese-based techniques can improve technical success of CTO PCI in the U.S. without adversely impacting patient outcomes.

Acknowledgments
The authors thank Dr. Masahiko Ochiai and Dr. Etsuo Tsuchikane for innovations in CTO PCI and mentoring operators in this study; Drs. Takahiko Suzuki, Osamu Katoh, the late Dr. Hideo Tamai, and many others for CTO PCI innovations and teaching this discipline. In addition, the authors thank Drs. Pete Beglin, Andrew Coletti, and James T. DeVries for contributions to this investigation.

Reprint requests and correspondence: Dr. Craig A. Thompson, Cardiology Section, Department of Medicine, Yale University School of Medicine, New Haven, Connecticut 06520-8017. E-mail: Craig.Thompson@Yale.edu.

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Key Words: angioplasty ■ stents ■ chronic total occlusion ■ retrograde ■ angiography ■ collateral.