The Safety and Feasibility of Bilateral Radial Approach in Chronic Total Occlusion Percutaneous Coronary Intervention

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SUMMARY

Few studies have reported results for transradial (TR) percutaneous coronary intervention (PCI) for chronic total occlusion (CTO) lesions. The purpose of this study was to evaluate the feasibility and safety of bilateral radial PCI for CTO lesions.

Eighty-five consecutive patients with CTO lesions received PCI via a bilateral TR approach. A high radial artery puncture (10-15 cm above styloid process) accommodating a 7 Fr catheter (85 cm long) was used for a retrograde approach, and a 6 Fr catheter was used in the other radial artery for an antegrade approach. Retrograde wiring was conducted primarily or after failure of antegrade wiring. Mean duration of CTO was 42.8 ± 54.9 months. Vessels with occlusions attempted were the left anterior descending artery (40.0%; 34/85), right coronary artery (58.8%; 50/85), and left circumflex artery (1/85). PCI re-attempts were made in 41.2% of the cases. The overall success rate was 87.1%. Retrograde wiring was successful in 61/85 cases (71.8%), via septal collaterals followed by epicardial collaterals and saphenous vein graft. There were no major complications (30 day in-hospital death, Q wave myocardial infarction, or emergency bypass surgery), or serious access site complications.

For experienced TR-PCI operators who are already doing complex TR coronary interventions, the bilateral radial approach for CTO lesions appears feasible and safe. (Int Heart J 2011; 52: 131-138)

Key words: Antegrade, Chronic total occlusion, Percutaneous coronary intervention, Retrograde

The most challenging lessons learned in the recent era for interventional cardiologists may have come from the use of percutaneous coronary intervention (PCI) for chronic total occlusion (CTO). Successful recanalization of CTO in patients with viable myocardium may reduce angina symptoms, decrease the need for bypass surgery, and may improve long-term survival.¹⁻³⁾ PCI instruments and the techniques for CTO lesions have improved over time,⁴⁾ and excellent outcomes have been achieved in multiple pilot studies, especially with the combined use of drug-eluting stents.⁵⁻⁷⁾

The most significant improvement in PCI for CTO of coronary vessels has been the introduction of the retrograde approach via bypass grafting⁸⁾ and epicardial collaterals. Septal collaterals have also been utilized in the treatment of CTO lesions.⁹⁾ The combined use of the traditional antegrade approach and the newly-developed retrograde approach has markedly increased the overall success rate, while not increasing the rate of major complications.¹⁰⁻¹⁴⁾

The transfemoral arterial approach (TFA) is the world-wide accepted method for CTO interventions because the artery can accommodate a larger guiding catheter, and hence provides better support and a larger working space. However,

the conventional TFA has several clinical and anatomical limitations including distal abdominal aortic disease, very tortuous or occluded ilio-femoral arteries, morbid obesity, and long period of bed rest required after the procedure. Significant hemostatic difficulties can occur with the TFA in obese patients, which may increase the risk of groin complications,¹⁵⁾ and lead to longer hospitalization. An alternative approach for CTO interventions that addresses these limitations is therefore needed.

The transradial approach (TRA) for PCI was introduced in 1993, and growing evidence has shown its benefits to include earlier ambulation, shorter hospital stay, lower medical cost, fewer access site complications, and patient preference. The popularity of the TRA for PCI varies with country, and although a longer learning curve of TRA has been reported, in places such as Canada, Europe, and Asian regions the TRA for PCI comprise from 40% to 60% of all PCI cases. The usefulness of the TRA for complex PCIs such as for unprotected left main disease, or stenting for carotid artery stenosis, has been proven by other studies of its feasibility and safety.^{16,17)} An acceptable success rate of the TRA for CTO lesions has also been published in several case reports.

The aim of the present pilot study was to evaluate the

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safety and feasibility of PCI via a bilateral forearm approach (transradial, transbrachial, and transulnar) in patients with coronary CTO lesions.

METHODS

The transradial (TR) PCI program was begun at our institution in 1994, and the TRA became our preferred method (> 95%) for routine PCIs since the year 2000. Each subject provided written informed consent, and the study protocol was approved by the hospital's Internal Research Board committee.

Patient enrollment and exclusion criteria: A diagram of the study enrollment is shown in Figure 1. Enrollment criteria were a documented CTO lesion which was defined as thrombolysis in myocardial infarction grade (TIMI) of 0 for more than 3 months, with the presence of typical angina or reversible myocardial ischemia in a thallium stress study. Exclusion criteria were: 1) a history of acute or recent stroke (< 2 months), 2) acute or recent myocardial infarction (MI), 3) surgery or trauma within the preceding 2 months, 4) unfavorable anatomy for the radial approach such as subclavian or innominate artery tortuosity and/or stenosis, and 5) positive Allen's test in both arms. From May 2006 to May 2010, a total of 85 consecutive patients with CTO of coronary vessels were enrolled prospectively and underwent PCI via an antegrade/retrograde approach.

Definitions: CTO was defined as described earlier. The duration of occlusion was estimated by the history of angina, history of MI in the same territory, or previous angiography. Procedure success was defined as successful guidewire and balloon crossing, with or without final stenting, the presence of a final TIMI 3 flow, and a residual diameter stenosis of < 30%. Contrast-induced acute kidney injury (CIAKI) was defined as an increase of baseline serum creatinine concentration of at least 0.5 mg/dL, or at least 25%, within 48 to 72 hours after exposure to contrast media. Major adverse cardiac events (MACE) were defined as death, MI (Q or non-Q wave), or urgent revascularization during the same admission. Urgent revascularization was defined as emergency bypass surgery, or repeat PCI of the same target vessel within 24 hours. Retrograde success was defined as successful passage of the guidewire through collaterals to the distal part of the CTO vessel, without damage to the collaterals such as spasm or perforation.

Procedure and protocol, selection of puncture site: Both radial arteries were evaluated by either Allen's test or Doppler ultrasonography before the procedure. The larger vessel was selected for the high radial arterial (T-HRA) approach, using a 7 Fr guiding catheter. The other radial was selected for the ordinary TRA using a 6 Fr guiding catheter. The T-HRA approach was defined as a puncture site 10 cm above the styloid process.¹⁷⁾ A 7 Fr and a 6 Fr arterial sheath were then inserted into the radial arteries following successful puncture. A transbrachial arterial approach (TBA) or transulnar arterial access (TUA) was utilized for patients either taller than 175 cm, or with one or more of the following: diameter of both radial arteries too small, weak or absent pulsations at the high-radial level, or an ulnar artery diameter larger than the radial artery diameter. A solution consisting of a mixture of 200 μ g nitroglycerin and 5,000 U heparin was given intra-arterially via the sheath.

Selection of guiding catheter: A 6 Fr Ikari IL 3.5 guiding cath-

eter (Terumo, Tokyo) or a 6 Fr Kimny Mini-radial guiding catheter (Boston Scientific, Grove, MN, USA) were the catheters primarily used in the antegrade approach. A 7 Fr 85 cm

Figure 1. Flowchart of patient enrollment.

Figure 2. An example of successful controlled antegrade and retrograde subintimal tracking (CART) technique, complicated by donor vessel (left main) dissection. **A)** Baseline angiogram of the right coronary artery (RCA) revealed chronic total occlusion (CTO) at the proximal RCA (6 Fr AL1 guiding catheter). The mid- to distal RCA (white arrows) was supplied by intracoronary collaterals (black arrows). **B)** Baseline angiogram of the left anterior descending (LAD) artery and left circumflex artery (LCX) showed patent vessels with multiple septal collaterals (black arrows) to the distal RCA and posterior descending artery (PDA) (white arrows). **C)** With the support of a transit microcatheter (Cordis, USA), a Fielder FC guidewire (Asahi, Japan) was successfully passed from the LAD (black arrows) through selected septal branches (white arrows) to the PDA (black dotted arrows). The guidewire tip in the true lumen was confirmed by antegrade contrast injection (white dotted arrows). **D)** Both the retrograde wire (Miracle 6g; Asahi, Japan) (black arrows) and antegrade wire (Miracle 6g) (black dotted arrows) were advanced into the false lumen at the proximal RCA. CART was performed by subsequent retrograde balloon dilatation (Maverick 2.0 $\times$ 20 mm; Boston Scientific, USA) at 14 atm (white arrows). **E)** The antegrade wire (Conquest 9g; Asahi, Japan) was successfully advanced to the RCA true lumen (black arrows). **F)** Final result after 3 drug-eluting stents (Taxus Liberte 2.75 $\times$ 25 mm, 3.0 $\times$ 32 mm, and 3.0 $\times$ 32 mm; Boston Scientific, USA) were deployed from the distal RCA to the proximal RCA under intravascular ultrasound (IVUS) guidance. **G)** Unfortunately, the final check of the left coronary artery created a left main (LM) dissection (black arrows) with the 7 Fr BL3.5 guiding catheter (Terumo, Japan), which extended up to the ascending aorta (white arrows). **H)** After T-stenting the LM-LCX (Zeta 4.0 $\times$ 38 mm; Abbott, USA) and LAD (Taxus Liberte 3.0 $\times$ 20 mm) and final kissing technique, the LAD and LCX showed normal flow with a good angiographic result. (**A, C-D, G,** right anterior oblique view; **B, H,** right anterior oblique cranial view; **E-F,** left anterior oblique cranial view.)

long BL 3.5-4 or AL 1-2 short guiding catheter (Terumo) was selected for the retrograde approach according to each individual patient. After successful engagement of both guiding catheters, a second bolus of 5,000 U heparin was given via the catheters.

Bilateral simultaneous coronary injections: At least two perpendicular projections with a biplane cine-machine were obtained, and the most proper view for the CTO intervention was selected by using simultaneous bilateral coronary injections.

Selection of guidewire: Guidewire selection for the antegrade approach was decided by each operator after baseline coronary angiography. The guidewires ranged from those with usual stiffness such as Runthrough Floppy (Terumo, Japan) or Rinato wires (Asahi, Tokyo), hydrophilic wires such as Pilot (Abbott, Abbott Park, IL, USA) or Fielder wires (FC or XT; Asahi), and stepwise harder-tip wires such as Miracle (3, 4.5, 6, 12 gm; Asahi) or Conquest wires (9, 12, or 20/8 gm; Asahi). The selected guidewire for the antegrade approach was placed at the proximal cap of the CTO site with a 1.8 F microcatheter (Finewire; Terumo). The guidewires used for the retrograde approach were either Fielder-FC or Fielder-XT (Asahi), and were supported with a microcatheter or the smallest profile of

over-the-wire balloon (Ryuji 1.25 × 10 mm, 135 cm, or 150 cm; Terumo).

Bilateral forearm approach for CTO intervention, retrograde and antegrade approaches: The reasons for attempting a retrograde approach were determined by the operator, and were typically because of a failure of the antegrade approach (previously or the same procedure), or because of unfavorable anatomy for antegrade wiring. Retrograde routes ranged from septal channel collaterals, epicardial collaterals, saphenous vein grafts (SVG), or the left internal mammary artery (LIMA). Collateral selection was made by further super-selective contrast injection via the microcatheter into the collaterals. Fielder FC or Fielder XT guidewires (Asahi) were carefully passed through the collaterals in a stepwise manner. After the guidewire was successfully advanced into the distal part of the CTO vessel, retrograde wiring was attempted with hydrophilic wires, with subsequent gradual stepping-up of the wire-tip strength, such as with Miracle 3-6 gm or Conquest-pro 9-12 gm wires. Different retrograde methods included the 1) kissing wire technique, 2) controlled antegrade and retrograde subintimal tracking (CART) technique (Figure 2), and 3) reverse CART technique or knuckle wire technique were used alone or in combination. After the retrograde wire had passed the occluded segment, the retrograde wire was manipulated into the antegrade guiding catheter, either for balloon anchoring or for externalization of the wire, by changing the original 190 cm wire into a 300 cm long wire through the microcatheter (Figure 3).

Stepwise balloon angioplasty was performed via the antegrade or retrograde route, and then an antegrade soft-tip wire was advanced into the distal portion of the occluded vessel along with the retrograde wire, or by using a "Crusade" (Kaneka, Corp) multifunction probing catheter. Next, an intravascular ultrasound assessment of the occluded vessel was performed for preparation of subsequent stenting. If all of the retrograde methods failed, an antegrade approach using a stiffer wire or parallel-wire technique was attempted as the last resort. A Tornus drilling catheter or a Rotablator catheter was considered if the lesion could not be crossed with the balloon un-crossing or balloon popping could not be achieved (Figure 3). After successful balloon dilatation, either a bare-metal stent (BMS) or drug-eluting stent (DES) was deployed, based on the patient's preference. (General health insurance guidelines in Taiwan only reimburse for BMS. The additional cost of a DES has to be paid for by the patient.)

Medications: Patients were pretreated with oral aspirin (100 mg/day). Patients were also pretreated with a loading dose of clopidogrel (300 or 600 mg), 4 to 12 hours before the procedure. A postprocedure dose of clopidogrel (300 mg) was administered, and then 75 mg/day was prescribed for at least 9 months following implantation of DES, or at least 3 months after BMS deployment

Statistical analysis: Continuous variables are reported as the mean ± standard deviation, while categorical variables are reported as frequencies. Categorical variables were compared between groups by the chi-square test. A *P*-value of < 0.05 was considered statistically significant. Statistical analysis was performed using SPSS version 13.0 software (SPSS, Chicago, IL, USA).

Figure 3. Example of successful retrograde externalization and antegrade rotablation via epicardial collaterals. **A)** Baseline angiogram of the left anterior descending (LAD) artery showed chronic total occlusion (CTO) at the mid-LAD artery without a visible stump (black arrows), and prior stent at the ostium of the left main (LM) to left circumflex (LCX) artery without in-stent restenosis. **B)** Baseline angiogram of the right coronary artery (RCA) showed epicardial collaterals from a tortuous right ventricular branch (RV) (black arrows) to the distal LAD artery (black dotted arrows). **C)** Antegrade approach using a Miracle 3 wire resulted in dissection (black arrows). **D)** Retrograde approach with a Finewire microcatheter (Terumo, Japan) and Fielder FC guidewire successfully advanced from the right ventricle (RV) branch (black arrows) through an epicardial collateral to distal to the LAD artery true lumen (black dotted arrows). The guidewire was able to pass through CTO segment and then was inserted into the antegrade guiding catheter (white arrows). **E)** Using a Maverick 2.0 × 20 mm balloon anchored to the retrograde wire (black arrows), a Ryuji 1.25 × 10 mm over-the-wire balloon (Terumo, Japan) was inflated at the mid- to proximal LAD artery to 16 atm (black dotted arrow). The guidewire was successfully changed to a Rinato 300 cm guidewire (Asahi, Japan) to allow externalization of the wire out of the antegrade guiding catheter. **F)** Due to severe calcification of the LAD artery at the occluded segment, a Finewire microcatheter was advanced to the distal LAD artery true lumen, and changed to a 0.009 Rota-wire (black arrows). **G)** Rotablation was initiated with a 1.5 mm Rota burr for the calcified CTO lesion. **H)** After T-stenting with two bare metal stents (Vision 2.5 × 28 mm (Abbott, USA), Zeta 3.0 × 38 mm) from the mid-LAD to the ostium of the LAD, and final kissing angioplasty from the LM to both the LAD and LCX arteries, good results were obtained. (**A, C-H**, right anterior oblique cranial view; **B**, left anterior oblique cranial view.)

RESULTS

Patient population: The patient population included 85 patients (mean age, 59.7 ± 11.1 years; 94.1% male) who underwent CTO revascularization using a bilateral forearm access and combined antegrade and retrograde approaches. Table I shows the demographic and baseline clinical data of the 85 patients. The retrograde approach was successful in 61 patients and unsuccessful in 24 patients. The retrograde approach success and failure patients did not differ significantly in body weight, body height, and baseline creatinine level. The incidences of risk factors, such as hypertension, diabetes mellitus, hyperlipidemia, and current smoking were similar in both groups. Forty-one percent of the patients had a history of MI, and 7.1% of the patients had a history of bypass surgery. The mean left ventricular ejection fraction, as determined by two-dimensional echocardiography, was $54.8 \pm 11.3\%$. The mean duration of CTO was 42.8 ± 54.9 months, and the longest duration was 240 months. Table I shows the 3 major reasons for attempting the retrograde approach. Re-attempt after prior antegrade failure accounted for 44.7% of the cases, CTO morphology unfavorable for the antegrade approach accounted for 45.9% of the cases, and in 9.4% of the cases a retrograde approach was attempted immediately after failure of primary antegrade wiring.

Angiographic characteristics and measurements: Table II summarizes data regarding the access site, arterial sheath size, baseline angiographic characteristics, and the procedure outcomes of the 85 patients. The target lesion was in the right cor-

onary artery (RCA) in 58.8% of the cases, and the left anterior descending artery (LAD) in 40% of the cases. There was only one patient who underwent left circumflex (LCX) CTO intervention. There were 81 patients (95.3%) in whom antegrade access via the usual radial access was used, and 6 Fr guiding catheters were used in 77 of these patients. There were 66 patients (89.4%) in whom a retrograde approach via high radial access was used, and 7 Fr guiding catheters were used in 68 of the patients (80%). There were no differences between patients with retrograde success or failure with respect to access site, arterial sheath size, and the target occluded vessels.

Angiography revealed proximal tortuosity of the occluded vessel in 19 patients (22.4%), and a side branch at the occlusion site in 51 patients (60.0%). Thirteen patients (15.3%) had heavy calcifications, as verified with fluoroscopic examination. However, there was no direct evidence indicating these angiographic characteristics might affect retrograde success. A “blunt stump” at the occlusion site was present in 62.3% of retrograde success patients, which was higher than that of the retrograde failure patients (37.5%, $P = 0.038$) (Table II). As

Table I. Baseline Demographic Characteristics

	All patients (n = 85)
Demographics	
Age, years	59.7 ± 11.1
Male	80 (94.1)
Body weight, kg	73.0 ± 11.6
Body height, cm	165.1 ± 6.0
Creatinine, mg/dL	1.3 ± 1.1
Risk factors	
Diabetes mellitus	27 (31.8)
Hypertension	72 (84.7)
Cholesterol > 200 mg/dL	19 (22.4)
Current smoking	41 (48.2)
Comorbidity	
Previous MI	35 (41.2)
Previous CABG	6 (7.1)
One-vessel disease	36 (42.4)
Two-vessel disease	22 (25.9)
Triple vessel disease	27 (31.8)
LVEF (%)	54.8 ± 11.3
History of CTO, months	42.8 ± 54.9
Reasons for retrograde approach	
Second attempt after prior antegrade failure	38 (44.7)
CTO morphology unfavorable	39 (45.9)
Antegrade failure then switch to retrograde	8 (9.4)
Retrograde attempt	
Retrograde guidewire successful crossing	61 (71.8)
Retrograde guidewire failed crossing	24 (28.2)

Data are presented as mean $\pm$ SD or number (%) of patients. MI indicates myocardial infarction; CABG, coronary artery bypass graft; LVEF, left ventricle ejection fraction; and CTO, chronic total occlusion.

Table II. Angiographic Characteristics in Retrograde Success and Failure Groups

	All patients (n = 85)	Retrograde Success (n = 61)	Retrograde Failure (n = 24)	P
Target CTO Vessel				
LAD	34 (40.0)	22 (36.0)	12 (50.0)	0.238
RCA	50 (58.8)	39 (63.9)	11 (45.8)	0.127
LCX	1 (1.2)	0 (0)	1 (4.2)	0.109
Antegrade Access Site				
Radial	81 (95.3)	57 (93.4)	24 (100)	0.199
Ulnar	2 (2.4)	2 (3.3)	0 (0)	0.369
Brachial	2 (2.4)	2 (3.3)	0 (0)	0.369
Antegrade Sheath Size				
5 Fr	4 (4.7)	3 (4.9)	1 (4.2)	0.883
6 Fr	77 (90.6)	55 (90.2)	22 (91.7)	0.831
7 Fr	4 (4.7)	3 (4.9)	1 (4.2)	0.883
Retrograde Access Site				
High Radial	76 (89.4)	53 (86.9)	23 (95.8)	0.227
High Ulnar	5 (5.9)	4 (6.6)	1 (4.2)	0.673
Brachial	4 (4.7)	4 (6.6)	0 (0)	0.199
Retrograde Sheath Size				
6 Fr	17 (20.0)	11 (18.0)	6 (25.0)	0.470
7 Fr	68 (80.0)	50 (82.0)	18 (75.0)	0.470
Angiographic Finding				
Proximal Tortuosity	19 (22.4)	15 (24.6)	4 (16.7)	0.430
Side Branch at Occlusion	51 (60.0)	36 (59.0)	15 (62.5)	0.768
Heavy Calcification	13 (15.3)	9 (14.8)	4 (16.7)	0.825
Morphology of Stump				
Tapered Stump	20 (23.5)	12 (19.7)	8 (33.3)	0.181
Blunt Stump	47 (55.3)	38 (62.3)	9 (37.5)	0.038
No Stump	18 (21.1)	11 (18.0)	7 (29.2)	0.258
Collaterals Grade				
Grade 1	41 (48.2)	29 (47.5)	12 (50.0)	0.838
Grade 2	37 (43.5)	25 (41.0)	12 (50.0)	0.450
Grade 3	7 (8.2)	7 (11.5)	0 (0)	0.083
Corkscrew Type	22 (25.9)	9 (14.8)	13 (54.2)	<0.001

Data are presented as mean $\pm$ SD or number (%) of patients. CTO indicates chronic total occlusion; LAD, left anterior descending artery; RCA, right coronary artery; LCX, left circumflex artery; and Fr, French.

Table III. PCI Results in Retrograde Success and Failure Groups

	All patients (n = 85)	Retrograde Success (n = 61)	Retrograde Failure (n = 24)	P
Collaterals Used				
Septal Collaterals	69 (81.2)	48 (78.7)	21 (87.5)	0.350
Epicardial Collaterals	9 (10.6)	6 (9.8)	3 (12.5)	0.719
Bypass Grafts	7 (8.2)	7 (11.5)	0 (0)	0.083
Retrograde Techniques				
CART	25 (29.4)	25 (41.0)	-	-
Reverse CART	7 (8.2)	7 (11.5)	-	-
Marker or Kissing Wire	37 (43.5)	37 (60.7)	-	-
Knuckle Wire	5 (5.9)	5 (8.2)	-	-
Externalization	8 (9.4)	8 (13.1)	-	-
IVUS Guided Puncture	2 (2.4)	2 (3.3)	-	-
Total Guidewire Used	4.9 ± 1.5	5.0 ± 1.5	4.6 ± 1.3	0.868
Tornus Used	5 (5.9)	4 (6.6)	1 (4.2)	0.673
Rotablation Used	1 (1.2)	1 (1.6)	0 (0)	0.528
Occlusion Lesion Length	56.3 ± 19.3	60.5 ± 18.5	45.7 ± 17.5	0.200
Total Procedure Time	161.5 ± 54.4	162.5 ± 56.6	159.2 ± 49.3	0.327
Fluoroscopy Time	70.2 ± 32.3	70.9 ± 32.1	68.4 ± 33.4	0.579
Contrast Volume	440.3 ± 186.3	413.6 ± 159.1	508.1 ± 232.6	0.039
Procedure Success	74 (87.1)	58 (95.1)	16 (66.7)	< 0.001

Data are presented as mean ± SD or number (%) of patients. PCI indicates percutaneous coronary intervention; CART, controlled antegrade and retrograde subintimal tracking; and IVUS, intravascular ultrasound.

Table IV. Major and Access Site Complications in Retrograde Success and Failure Groups

	All patients (n = 85)	Retrograde Success (n = 61)	Retro- grade Failure (n = 24)	P
Complications				
Cardiac tamponade	3 (3.5)	1 (1.6)	2 (8.3)	0.132
GI bleeding	0 (0)	0 (0)	0 (0)	1.000
Contrast-induced AKI	2 (2.4)	1 (1.6)	1 (4.2)	0.489
Aortic cusp dissection	1 (1.2)	1 (1.6)	0 (0)	0.528
Donor vessel dissection	3 (3.5)	3 (4.9)	0 (0)	0.269
Collaterals perforation	7 (8.2)	3 (4.9)	4 (16.7)	0.076
Perforation needing coil insert	2 (2.4)	2 (3.3)	0 (0)	0.369
Perforation not needing coil	2 (2.4)	2 (3.3)	0 (0)	0.369
Access Site Complications				
Forearm ecchymosis	3 (3.5)	1 (1.6)	2 (8.3)	0.132
Blood transfusion	0 (0)	0 (0)	0 (0)	1.000
Access site surgery	0 (0)	0 (0)	0 (0)	1.000

Data are presented as mean ± SD or number (%) of patients. PCI indicates percutaneous coronary intervention; CABG, coronary artery bypass graft; GI bleeding, gastrointestinal bleeding; and Contrast-induced AKI, contrast-induced acute kidney injury.

for cases with a “tapered end” or “no stump” at the occlusion site, there was no significant difference between the groups. There was no difference in either grade 1 or grade 2 collaterals between retrograde success or retrograde failure patients, and in all 7 patients with grade 3 collaterals we were able to achieve retrograde wire success. The only significant difference in collaterals between the groups lies in whether they are the corkscrew type or not (retrograde success 14.8% versus retrograde failure 54.2%, respectively, $P < 0.001$).

Table V. Clinical and In-Hospital Outcomes in Retrograde Success and Failure Groups

	All patients (n = 85)	Retrograde Success (n = 61)	Retro- grade Failure (n = 24)	P
In-hospital adverse outcomes				
All-cause death	0 (0)	0 (0)	0 (0)	1.000
Cardiac death	0 (0)	0 (0)	0 (0)	1.000
Q-wave MI	0 (0)	0 (0)	0 (0)	1.000
Non-Q-wave MI	2 (2.4)	2 (3.3)	0 (0)	0.369
Stroke	0 (0)	0 (0)	0 (0)	1.000
Emergent PCI	1 (1.2)	1 (1.6)	0 (0)	0.528
Emergent CABG	0 (0)	0 (0)	0 (0)	1.000
Stent thrombosis	1 (1.2)	1 (1.6)	0 (0)	0.528
Clinical outcomes				
Hospital stay, days	4.6 ± 5.8	4.1 ± 3.3	5.8 ± 9.5	0.015
Learning curve analysis				
Initial 25 patient success	18/25 (72.0)	-	-	0.008
Later 60 patient success	56/60 (93.3)	-	-	

Data are presented as mean ± SD or number (%) of patients. MI indicates myocardial infarction.

PCI techniques and procedure outcomes: Table III summarizes data regarding the retrograde technique and procedure outcomes during PCI. Septal channel collaterals were used primarily (69 patients, 81.2%), followed by epicardial collaterals (9 patients, 10.6%), and bypass grafts (7 patients, 8.2%). Success was achieved in 7 bypass grafts used for the retrograde route. The marker or kissing wire technique was used in 37 patients (43.5%), and CART or reverse CART was used in 25 patients (29.4%), which comprised 73% of the total retrograde procedures. The average number of guidewires used, occlusion

length, total procedure time, and total fluoroscopy time were not different between retrograde success or failure patients. The average contrast volume used in the 85 patients was 440.3 ± 186.3 mL, and the retrograde failure group received a significantly larger volume of contrast than the retrograde success group (508.1 ± 232.6 mL versus 413.6 ± 159.1 mL, respectively, $P = 0.039$). The overall PCI procedure success rate was 87.1% (74/85). The retrograde success group had a significantly higher success rate than the retrograde failure group (95.1% versus 66.7%, respectively, $P < 0.001$).

In-hospital clinical events and 30-day follow-up: Table IV summarizes data regarding in-hospital cardiac events and access site complications. Three patients experienced cardiac tamponade after PCI, and were treated by percutaneous pigtail catheter drainage. Two patients experienced contrast-induced nephropathy, and both recovered after conservative treatment. One patient experienced aortic cusp dissection during PCI, which was treated with a coronary cover-stent. There were no differences between retrograde success and failure patients with respect to donor vessel dissection, collateral perforation, coronary perforation, and coil embolization or cover-stent usage. There were minimal access site complications; only 3 patients experienced forearm ecchymosis after the PCI procedure, and none of them required emergent blood transfusion or experienced forearm compartment syndrome.

Table V summarizes data regarding the MACE and 30-day clinical outcomes of the 85 patients. There were no in-hospital deaths, Q wave MI, stroke, or 30-day emergent CABG, but one patient required an emergent rescue PCI due to acute (< 24 hours) in-stent thrombosis. Two patients experienced non-Q wave MIs. One patient had a catheter-tip induced left main dissection, which was complicated with LAD artery perforation and cardiac tamponade. One patient who had an anomalous RCA (originating from the left cusp) experienced RCA ostial dissection which extended to the ascending aorta. The dissection was treated successfully with bare metal stenting. The final result of this patient was acceptable; a limited intramural hematoma at the ascending aorta remained after stenting, but the hematoma had completely resolved as noted on a 3-month computed tomography follow-up study. The mean hospital stay was 4.6 ± 5.8 days, and the retrograde failure group (5.8 ± 9.5 days) had a relatively longer stay than that of the retrograde success group (4.1 ± 3.3 days, $P = 0.015$). There was a significantly lower success rate (18/25, 72.0%) in our early learning period; however, a significantly higher success rate was achieved in a later period (56/60, 93.3%, $P = 0.008$) (Table V).

DISCUSSION

In the modern era, PCI for CTO lesions with the presence of viable myocardium is well accepted by most cardiovascular interventionists. Newly-developed devices and techniques for CTO intervention have increased the success rate to 50% to 80% or higher.¹⁸⁾ Overall procedure success is highly dependent on successful antegrade or retrograde wiring across the occlusion. To the best of our knowledge, this is the first report with a significant number of consecutive patients that has evaluated the feasibility of a bilateral forearm approach for CTO intervention. The study results proved the feasibility and safety

of the bilateral forearm approach for PCI of CTO lesions, with a high procedure success rate of 87.1%, and a complication rate similar to that reported in studies using the standard femoral approach.^{7,19)}

Comparisons of the bilateral forearm approach for CTO intervention: The first retrograde approach for CTO lesions via bypass grafts was reported in 1990, and had a successful revascularization rate of 75%.⁸⁾ Thereafter, several case reports have described improvements in the technique and the evolving devices. Following the introduction of the CART technique using septal collaterals, the first report to examine the feasibility of the retrograde approach of PCI for CTO intervention was published in 2006.²⁰⁾ A subsequent report described a high success rate of passing retrograde collaterals (82%), and a high final success rate (84%) in 45 patients via the femoral approach.¹⁹⁾ Comparatively, the present study reported a similar final success rate of 87.1%, but a lower rate of passing retrograde collaterals (71.6%). As compared to the present study, two larger CTO interventional studies involving 157 patients¹⁰⁾ and 224 patients¹³⁾ reported similar final success rates of 84.7% and 90.6%, respectively. Our results also demonstrated that CTO interventions necessitated a learning curve, and it is very important for each operator to be familiar with the different techniques of the retrograde and antegrade approaches.

Comparison of complications with literature: Common complications in retrograde CTO interventions include a higher incidence of collateral channel perforation and a higher incidence of CIAKI, and retrograde CTO interventions are also associated with longer procedure and fluoroscopy times.⁷⁾ As compared to a previous study that reported a 3.8% incidence of septal collateral perforation and a 3.2% incidence of non-Q wave MI,¹⁰⁾ our study reported a higher incidence of septal collateral perforation (7.4%) and a lower incidence of non-Q wave MI (2.5%). Although we did use a larger amount of contrast during our CTO interventions (mean 442 mL versus 293 mL, respectively), there was no significant difference in post-procedure CIAKI between our patients (2.5%) and the 1.2% reported in a multicenter CTO registry of Japan.⁷⁾ The fluoroscopy time in the present study was relatively longer than that of the Japan CTO registry study (mean 70 minutes versus 45 minutes, respectively); however, none of our 85 patients developed radiation-induced dermatitis. The two studies, however, cannot be equally compared because most of the patients in the Japan CTO registry (74%, 392/528) underwent PCI only via an antegrade approach. Major in-hospital events, including emergent CABG or PCI, MI, stroke, cardiac tamponade and cardiac death, were similar between the present report and the other CTO studies.^{7,9-14,19,20)}

Prediction and prevention of complications: In our series, 7 patients had collateral perforation during PCI and all underwent a retrograde attempt via septal collaterals. Three (3/7, 42.9%) were corkscrew type collaterals. The reasons for the collateral perforation might be 1) severe angulated, tortuous and corkscrew like collaterals, 2) invisible collaterals or lack of a clear roadmap during guidewire crossing of the collaterals, or 3) the usage of a hydrophilic guidewire such as a Fielder FC wire. There are some key aspects with respect to preventing collateral perforation. First, the operator should be more careful when selecting collaterals that are severely angulated, tortuous, and corkscrew like. Second, the operator should use a super-selection angiogram (microcatheter in collaterals) as a roadmap.

Third, the operator should advance the hydrophilic guidewire as gently and carefully as possible.

One aortic cusp dissection and 3 coronary donor vessel dissections were found in our study. The aortic cusp dissection in one patient was due to a pre-existing coronary anomaly (right coronary artery CTO that originated from the left coronary cusp). One of the 3 patients (1/3, 33.3%) who suffered from donor vessel dissection had a pre-existing angiographically unstable plaque in the donor vessel (LM) and 3 had donor vessel dissection during an antegrade approach. Several things should be borne in mind to prevent aortic cusp dissection and donor vessel dissection. First, the operator should manipulate the guiding catheter carefully, especially when there is an anomalous origin. Second, the operator should always keep an eye on the donor vessel when initiating antegrade PCI. However, in our series, no correlation between these complications and TRA during CTO intervention was observed.

Forearm intervention, advantages and disadvantages: Although the TFA for CTO intervention is the first choice for most interventional cardiologists, our previous studies have proven the benefits of the TRA in complex coronary interventions.^{16,21,22} The presence of excellent clinical results support the use of the TRA, and the TFA may be avoided in special situations such as abdominal aortic atherosclerotic disease, severe aortoiliac disease, and previous ilio-femoral bypass graft placement. In bilateral approach CTO interventional studies, only the Japan CTO registry clearly mentioned the access site.⁷ In most patients in the Japan CTO registry, a femoral access was used for an antegrade approach (87.6%), and most often a sheath size of 7 Fr was used (82.0%). In our study, both antegrade and retrograde access (95.1% and 88.9%, respectively) were via the radial arteries. Other forearm arteries (ulnar or brachial artery) were used as an alternative when the radial artery was too small or the patient was taller than 175 cm. The most frequently used arterial sheath sizes in our study were 6 Fr (91.4%) for the antegrade approach and 7 Fr (79.0%) for the retrograde approach, and both are smaller than those used in the Japan CTO registry study. Although we did use a smaller guiding catheter for antegrade TRA CTO intervention, our final results were equivalent to femoral approach studies. In addition, the down-sizing of the arterial sheath may have the potential benefit of preventing forearm artery endothelial damage. Only 3 patients in our study had forearm ecchymosis, and none required a blood transfusion or vascular surgery. One important finding of the present study is the demonstration of a mean hospital stay of 4.6 days, which is the shortest among all of the published bilateral CTO interventional studies.^{7,9-14,19,20} Shorter hospital stays can lead to a reduction in total medical costs associated with the procedure.

Limitations of the bilateral forearm approach: There are 3 major limitations of the bilateral forearm approach. 1) Forearm arteries have potential anatomical variations such as looping or small accessory radial arteries, buckling of the innominate artery can occur, or tortuosity of the subclavian artery may be present, 2) Patients with end-stage renal disease may need further protection of the forearm arteries, and 3) The retrograde shorter guiding catheter (85-90 cm) is too short to reach the coronary ostia in patients who are taller than 175 cm. In our study, the primary size of the antegrade catheter used was a 6 Fr, which may greatly limit the techniques that can be used. A sheathless approach for CTO intervention using 7 Fr guiding

catheters in both arms may be a future direction, however, we have limited experience with this in our laboratory. Despite these limitations, the bilateral forearm approach for CTO intervention is safe and effective, especially for experienced TRA operators who are already performing complex PCIs via the radial approach.

Conclusions: The bilateral forearm approach for PCI of CTO lesions appears to be feasible and safe.

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