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A Novel Modification of the Retrograde Approach for the Recanalization of Chronic Total Occlusion of the Coronary Arteries

Intravascular Ultrasound-Guided Reverse Controlled Antegrade and Retrograde Tracking

Sudhir Rathore, MD,* Osamu Katoh, MD,* Etsuo Tuschikane, MD, PhD,* Akitsugu Oida, MD,† Takahiko Suzuki, MD,* Shimichi Takase, MD†

Toyohashi and Gumma, Japan

Objectives The study evaluates the feasibility and efficacy of the novel modification of the retrograde recanalization of the chronic total occlusion (CTO) of the coronary arteries by using intravascular ultrasound (IVUS)-guided reverse controlled antegrade and retrograde tracking (CART).

Background Despite improvement in the techniques and materials, CTO recanalization is still suboptimal. The CART procedure has improved success rates, but there are certain inherent technical uncertainties and risk with this procedure.

Methods This first series involves 31 patients, with 22 patients having previous failed attempts at CTO recanalization. All patients were treated with bilateral approach and using IVUS-guided reverse CART concept.

Results Successful recanalization of the CTO was achieved in all cases (100%). The access route was septal collateral in 20 (70%) cases and epicardial collateral in 11 (30%) cases. IVUS guidance was used successfully in 30 cases, and the channel dilator (microcatheter) was used in 27 cases. Guidewire injury and grade 1 perforation was seen in 3 (9%) cases, which were managed conservatively. There was no death, coronary artery bypass surgery, or pericardiocentesis in this group of patients. Mean fluoroscopy time was 65.84 ± 23.16 min, ranging from 31 to 106 min and total contrast volume used 321.32 ± 137.77 ml (range 115 to 650 ml).

Conclusions This first series describes a high success rate of CTO recanalization with IVUS-guided reverse CART in selected patients performed by an experienced operator. (J Am Coll Cardiol Intv 2010;3:155–64) © 2010 by the American College of Cardiology Foundation

From the *Department of Cardiology, Toyohashi Heart Center, Toyohashi, Japan; and the †Department of Cardiology, Takase Clinic, Gumma, Japan. Dr. Katoh has contributed toward the invention of a channel dilator and has co-ownership of the company that receives royalties from ASAHI, Japan.

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Chronic total occlusion (CTO) is seen commonly following coronary angiography in patients with symptomatic coronary artery disease (1–4). There are several studies showing the symptomatic and prognostic benefits of successful recanalization of the CTO lesions (4–8). They have been shown to improve angina status, survival, and left ventricular systolic function. Recently, drug-eluting stents have shown improved results by reducing repeat revascularization rates in these complex lesion subsets. Historically, the success rate of the CTO recanalization has been low (9–11) and is mainly due to the inability to pass the guidewire into the distal true lumen (12–15). Lately, several novel approaches including parallel wire (16), intravascular ultrasound (IVUS) guidance (17,18), and controlled antegrade and retrograde tracking (CART) (19) procedures have shown to improve success rates.

Retrograde techniques have shown promising results (20–25) with the utilization of retrograde collateral channels (CCs) in around 50% to 70% of the cases and thereby, allowing the guidewire to reach the distal end of CTO. The main reason of failure or limitation with this technique is the inability to cross and dilate these small and tortuous channels to facilitate delivery of balloon and wires in some patients. With the introduction of the channel dilator, the envelope is further pushed and the technique could be applied in small and tortuous CCs to gain retrograde entry.

Abbreviations and Acronyms

CART = controlled antegrade and retrograde tracking

CC = collateral channel

CTO = chronic total occlusion

IVUS = intravascular ultrasound

We describe here the novel modification of the retrograde technique where reverse CART procedure is attempted with the guidance of IVUS to achieve successful recanalization (IVUS-guided reverse CART). We describe the procedural details and in-hospital outcomes of the first series of patients with this novel technique.

Methods

Patient population and procedural protocol. All patients enrolled in this analysis underwent IVUS-guided reverse CART with the intention to treat for recanalization of coronary CTO lesion. A total of 31 consecutive patients who underwent IVUS-guided reverse CART between March 2007 and September 2008 are included in this study. The target procedures were mainly performed in Japan (27 patients), but also in Europe (4 patients) by a very experienced CTO operator. All patients have CTO in 1 or more native vessels and the indication of the procedure was angina or proven stress-related ischemia.

All procedures were performed by 1 main operator (O.K.) and other suboperators. The main operator performs 200 to 300 CTO cases per year with antegrade success rates of 85% to 90% (26). The operators have used the CART technique in a majority of the cases after antegrade failure since 2005 (15% of the total CTO cases) and more recently reverse CART has been applied in selected cases.

Limitations of CART procedure. The traditional CART procedure (18) involves creation of retrograde subintimal dissection and connects this with controlled antegrade dissection to enable the passage of a guidewire into the distal true lumen. This procedure uses a CC and subsequently delivers a balloon through this channel at the distal end of the CTO or inside the CTO to achieve subintimal dissection.

Although the creation of both antegrade and retrograde subintimal dissections facilitates the connection between both dissections and antegrade wire crossing, the ballooning for creating retrograde subintimal dissection is performed without the information on CTO vessel size and the position of the retrograde wire. In addition, the formation of the retrograde subintimal dissection and the position of the retrograde wire cannot be confirmed by antegrade or selective retrograde angiography. Therefore, the technical uncertainty and the risk remain in CART technique in terms of CTO crossing. We have recently reported the procedural details of retrograde techniques (23) and the common causes of retrograde failure is the inability to cross the CC with wire and balloon and the inability to achieve optimal subintimal dissection in around 25% of the cases. However, in the hands of the main operator (O.K.), failure of CART procedure is rare, but this takes time and it is subject to trial and error. This is also extremely difficult in large (>4.0 mm) vessels, and therefore we need IVUS-guided reverse CART.

To overcome the abovementioned difficulties with the CART procedure, several new techniques and equipment were developed. The Corsair channel dilator (Asahi Intecc, Aichi, Japan) has shown promising results in the maneuverability of the guidewire in the CTO segment after getting through a tortuous retrograde route. The CCs were delineated with selective antegrade injections to assess the connectivity with the recipient vessel. The guidewire, usually soft polymer coated wires (Fielder, Fielder FC, Fielder XT, Asahi Intecc) were introduced into the target CC with the backup of the channel dilator used as a microcatheter in a majority of the cases. The channel dilator has expanded the indication of retrograde approach by allowing access through tortuous and epicardial CCs (mainly epicardial channels located on the posterolateral wall) and more importantly, has given the potential to modify the retrograde procedure by improving the controlled movement of the retrograde wire.

Procedural details of IVUS-guided reverse CART. The steps involved in the IVUS-guided reverse CART procedure are as follows.

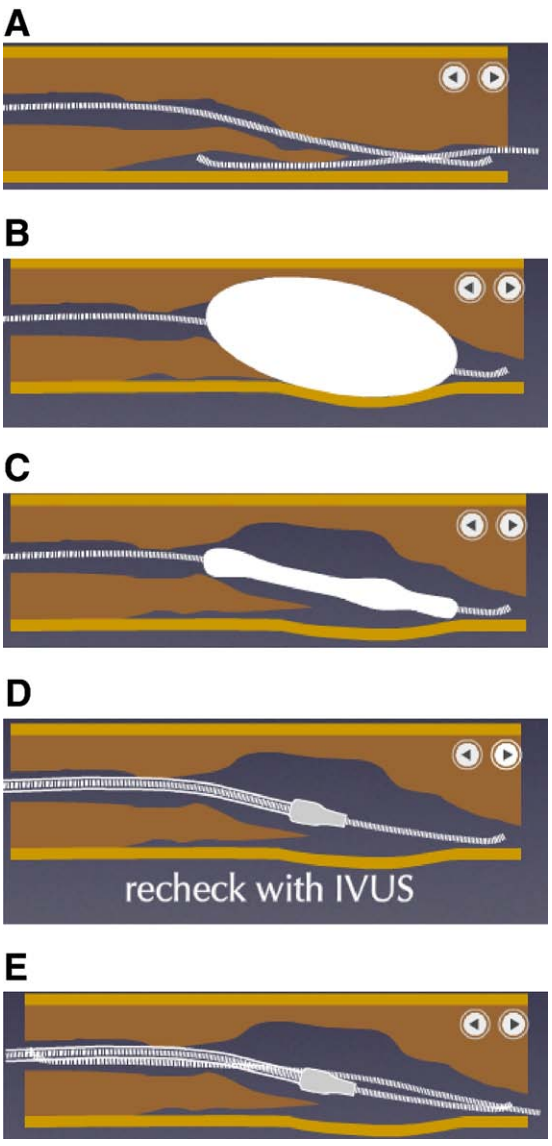

Figure 1. Schematic Diagram of IVUS-Guided Reverse CART

(A) Showing both antegrade and retrograde wire in subintimal space; **(B, C)** dilation of subintimal space with balloon on antegrade wire to make connection; **(D)** checking with intravascular ultrasound (IVUS) for the location of subintimal space; **(E)** retrograde wire passed from subintimal space into antegrade true lumen via connection made by antegrade balloon under IVUS guidance. **Right arrowhead** (►) indicates distal lumen, and **left arrowhead** (◄) indicates proximal lumen. CART = controlled antegrade and retrograde tracking.

1. The retrograde wire is tracked up to the distal end of the CTO as described earlier through the CC and into the CTO segment (Fig. 1A).
2. Thereafter, the antegrade wire is introduced into the CTO segment and the antegrade balloon dilation is performed either inside the vessel or in the subintimal space to create intimal and medial disruption. Then the antegrade subintimal space can be automatically connected with the retrograde subintimal space if the retrograde wire has already created the subintimal dissection. If not, the retrograde wire is handled toward the subintimal layer and thereby the retrograde wire can easily reach to the antegrade subintimal space. This facilitates the retrograde wire entry into the proximal true lumen via the channel created by the antegrade wire and balloon (reverse CART without IVUS guidance) (Figs. 1A to 1C and 1E).
3. There are 2 potentially difficult situations for CTO crossing with this concept. a) Antegrade ballooning does not make subintimal dissection if the balloon is positioned inside the intima and the balloon size is too small because balloon dilation may not cause intimal and medial disruption. Moreover, angiography cannot provide the information of the antegrade wire position (i.e., antegrade balloon position) and the optimal balloon size for making medial disruption. Therefore, antegrade channel and the retrograde channel cannot be automatically connected (Fig. 2A). In this situation, the antegrade channel has to be intentionally punctured by the retrograde wire for successful CTO crossing. This procedure is often difficult and unpromising just as with a conventional antegrade approach. b) Recoil of connecting subintimal channel sometimes occurs even if the connecting channel between the antegrade and the retrograde channel is successfully made with the antegrade balloon inflation. Moreover, the medial disruption with the antegrade balloon potentially causes bidirectional expansion of the subintimal dissection. This makes

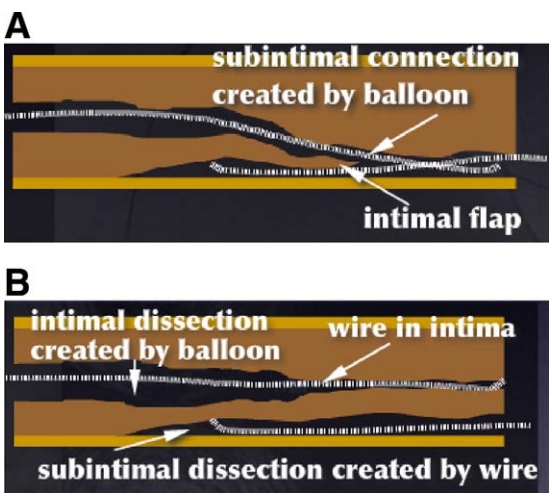

Figure 2. Schematic Diagram Showing Potential Difficult Situations With CART

Diagram shows potentially difficult situations with the CART technique. Abbreviations as in Figure 1.

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retrograde wire crossing difficult because in that situation, the wire easily migrates into the proximal subintimal space created by the antegrade balloon or the wire itself beyond the connecting channel (Fig. 2B).

4. These difficulties could be overcome by the use of IVUS. The use of IVUS after pre-dilation with small balloon (usually 2.0 mm) along the antegrade wire in CTO segment allows estimating the optimal balloon size of the antegrade balloon matching the vessel size for making medial disruption based on the information on a true CTO vessel size, plaque components, and its distribution. The risk of perforation is negligible if done following IVUS guidance and appropriate selection of balloon size. However, in the presence of calcified plaque, a smaller size balloon could be used to reduce any perforation risk. More importantly, the formation of medial disruption and the connecting channel could be checked by IVUS after the antegrade balloon inflation. If IVUS indicates the recoil of connection channel, redilation with a bigger balloon should be performed. IVUS also provides direct visualization of the position of the retrograde wire in the subintimal space. The retrograde wire could be handled under direct visualization of IVUS into the proximal true lumen (Figs. 1A to 1E).
5. The important step in this technique is to confirm the connecting channel, which is created by the antegrade balloon dilation, is open enough to allow passage of the retrograde wire into the proximal true lumen.
6. IVUS can provide direct visualization of the connecting channel after balloon dilation, and if the repeat recoil is observed, the 0.014-inch snare wire (Soutenir, Asahi Intecc) can be used at the recoil position to keep the connecting channel open by pushing the flap and minimizing the vessel injury (Figs. 3A to 3E).
7. This then allows the retrograde wire to be passed through this subintimal connection into the proximal true channel and the channel dilator can be negotiated into the proximal true lumen.
8. Subsequently, the guidewire can be crossed antegrade and the CTO segment could be dilated using antegrade balloon and recanalization would be achieved.

It should be emphasized that in the IVUS-guided reverse CART, the soft polymer-coated wires could be used to cross the subintimal connection, because the stiff CTO wires are unnecessary after the creation of a connecting channel is checked by IVUS. This also avoids complications such as vessel perforation or excessive expansion of the subintimal dissection. Another important precaution is to avoid contrast injections after creating antegrade subintimal dissection to prevent a spiral dissection. IVUS guidance is essential for a sophisticated retrograde approach until the retrograde wire has crossed into the proximal true lumen.

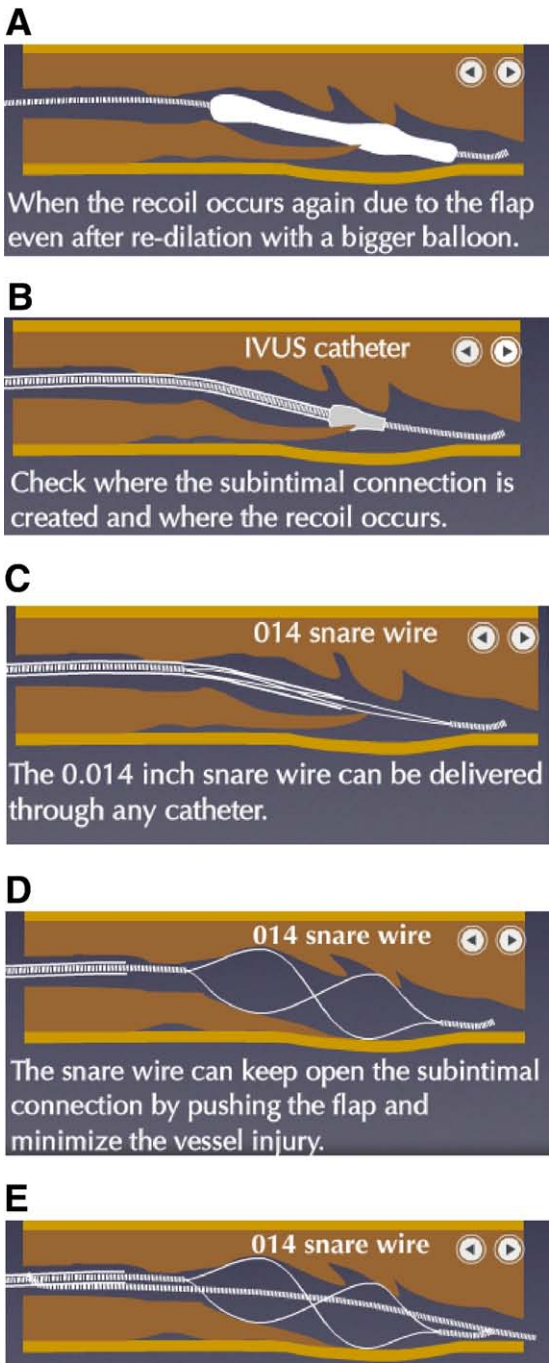

Figure 3. Schematic Diagram Showing Use of Snare Wire

(A to D) Showing the use of snare wire to keep the subintimal space open after antegrade balloon dilation and intravascular ultrasound (IVUS) confirmation; **(E)** retrograde wire crossed to the antegrade true lumen. **Right arrowhead** (►) indicates distal lumen and **left arrowhead** (◄) indicates proximal lumen.

Procedural details of retrograde approach and selection of CC. In all patients, the bilateral femoral approach for simultaneous bilateral coronary injection was used and weight-

adjusted heparin was administered to achieve activated clotting time >300 s. The procedure was then performed as described previously. A representative case is shown in Figure 4.

Definitions. Chronic total occlusion was defined as a Thrombolysis In Myocardial Infarction (TIMI) flow grade 0 of more than 3 months duration. The duration of the occlusion was estimated from previous angiographic data or clinical information (history of myocardial infarction or worsening of angina symptoms).

Technical success was defined as restoration of antegrade TIMI flow grade 3 and final residual stenosis of less than 30%.

Collateral channels were graded as: CC0 = no continuous connection between donor and recipient vessel; CC1 = continuous threadlike connection; and CC2 = continuous, small side branchlike connection (21).

Data collection. All baseline demographics, angiographic variables, and procedural details were collected prospectively. The analysis was performed retrospectively from the collected data.

Statistical analysis. Descriptive analysis was performed. Results are quoted as frequency or percentages for categorical data and mean ± SD for continuous variables.

Results

Success rates. Technical success was achieved in all 31 cases (100%). IVUS-guided reverse CART was the final strategy adopted in 29 cases and CART in 2 cases. The IVUS guidance was used in 30 cases, and IVUS could not be used in 1 patient because of nonavailability.

Baseline demographics. As shown in Table 1, mean age was 62 years with age ranging between 38 and 75 years. Majority of the patients were male with risk factors as shown. Just over half of the patients had 3-vessel disease and three-fourths of the patients had previous failed revascularization attempts by other operators.

Angiographic characteristics. The target vessel was the right coronary artery in the majority of the patients (80%), followed by left anterior descending and left circumflex coronary arteries as shown in Table 2. The mean length of the occluded segment was 44.72 ± 21.59 mm and the CTO stump morphology was blunt or abrupt in 84% of the patients. Moderate or severe calcification was observed in 12% of patients, bridging collaterals in 76% of patients and moderate or severe tortuosity in 48% of the patients.

Collateral channels used. Collateral channels used, retrograde techniques applied, and equipment used are mentioned in Table 2. Septal CCs were used in 20 (70%) patients, followed by epicardial channel used in 11 (30%) patients. The CC type was CC0, CC1, and CC2 in 9%, 48%, and 42% patients, respectively. Collateral channel was corkscrew-shaped in 27% of the cases. In this series, the CCs were crossed in all patients by intention to treat.

Guidewire selection. Soft polymer-coated guidewires were used in most of the patients to cross the CC (Fielder FC in 77% and Fielder X-Treme in 20% of cases). Channel dilator was used in a majority of the patients (87% cases) for collateral dilation and the 1.3-mm over-the-wire balloon was used in the remaining patients. The CTO segment was crossed with a soft wire in 38% of cases, and in the remaining cases, stiffer wires are used as shown in Table 3.

The final retrograde concept was reverse CART in 29 patients and CART in remaining 2 cases, in whom the reverse CART could not be applied because of a very tortuous antegrade CTO vessel, and the balloon could not be delivered. IVUS guidance was used in 30 patients, and snare wire was used in 4 patients.

Procedural complications. The guidewire perforation was observed in 3 (9%) cases. In the first case, the perforation was caused inside the CTO segment by the stiff antegrade wire, Miracle 3 (Asahi Intecc). This was managed with prolonged balloon compression and no pericardial effusion was noticed. In the 2 remaining patients, wire perforation was caused by guidewire in the CTO vessel and was managed conservatively. In 1 case, the guidewire (X-Treme, Asahi Intecc) was trapped inside the CTO from the retrograde route, which was finally released after antegrade dilation and with the help of the snare wire, with no post-procedure consequences. Minor ischemia was seen in the collateral territory following introduction of channel dilator in 2 patients, which was well tolerated.

The collateral channels were delineated with selective antegrade injections to assess the connectivity with the recipient vessel. None of the patients in this series underwent emergency coronary artery bypass graft surgery or pericardiocentesis. Mean fluoroscopy time was 65.84 ± 23.16 min, ranging between 31 and 106 min and total contrast volume used was 321.32 ± 137.77 ml (range 115 to 650 ml).

Discussion

This is the first reported series in which IVUS-guided reverse CART was applied to achieve successful recanalization in a selected group of patients by an experienced operator. The success rate in this series was 100% with no serious complication.

Inability of the guidewire crossing is the main reason of the procedural failure in CTO recanalization. Several attempts have been made recently to improve the recanalization rates by novel techniques. Retrograde use of the CC and approaching the CTO segment in the retrograde fashion has resulted in some success in a selected group of patients. Surmely et al. (19) described successful usage of septal CCs for the retrograde approach and described

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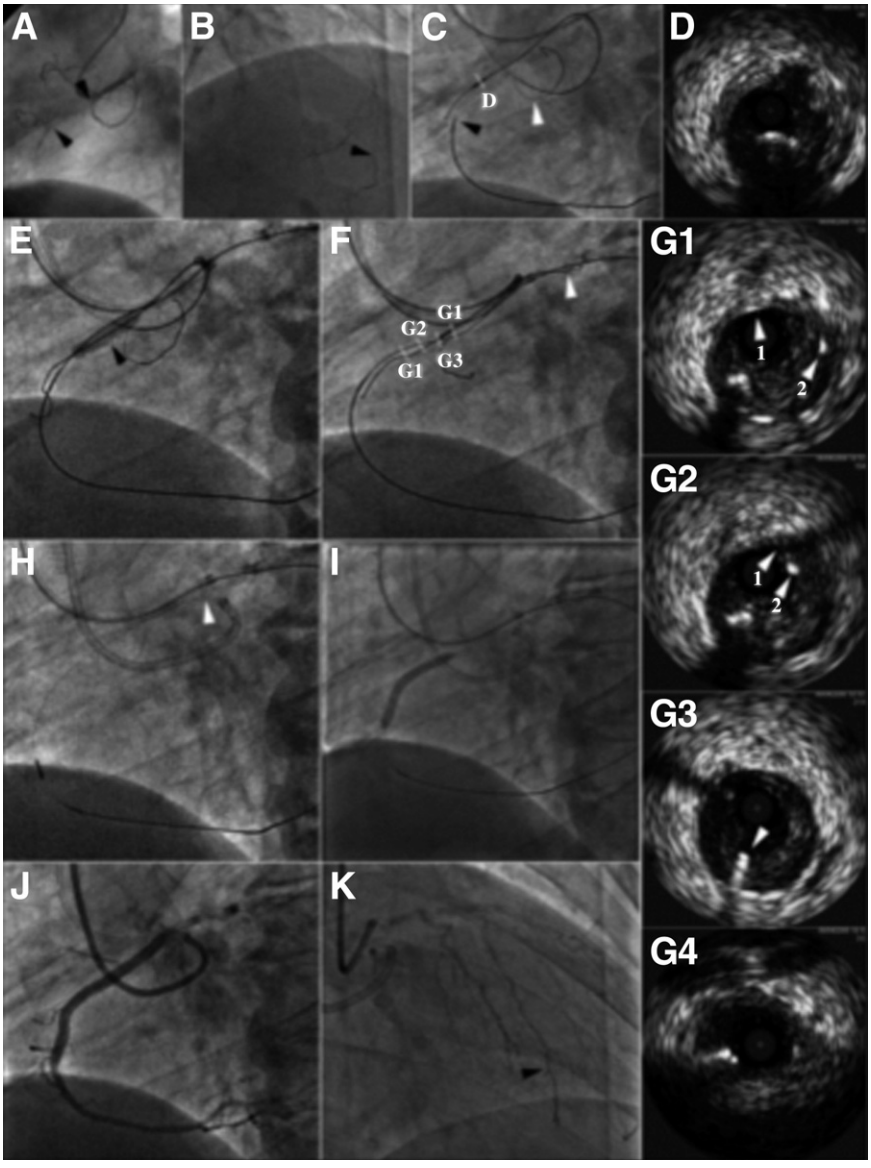

Figure 4. A Case of Reverse CART With IVUS Guidance

(A) Before procedure: the chronic total occlusion (CTO) is located in the proximal right coronary artery (between 2 **black arrows**) with an abnormal origin from the left sinus of Valsalva. **(B)** The continuous connection (CC2) is seen between the posterolateral branch of the left circumflex artery and the posterolateral branch of the right coronary artery **(black arrow)**. **(C)** The channel dilation catheter easily crossed the channel and was advanced to the distal end of the CTO **(black arrow)**. The anchor technique **(white arrow)** was applied to perform pre-dilation with 2.5 mm and to deliver the IVUS catheter. The IVUS catheter is positioned at the point **D**. **(D)** IVUS findings at the point **D**. The vessel size in the occluded segment was 5.0 mm and small calcification was seen at the point **D**. **(E)** As an antegrade balloon for creating subintimal dissection, a 4.5-mm balloon **(black arrow)** was selected according to the IVUS findings. **(F)** After creating the antegrade subintimal dissection with the 4.5-mm balloon, the retrograde wire (Fielder XT) easily crossed the CTO **(white arrow)** with IVUS guidance. **(G)** IVUS findings in each point (points **G1** to **G4**). **G1:** the subintimal dissection created with the 4.5-mm balloon is seen **(white arrow 1)**. The retrograde wire is located in the subintima **(white arrow 2)**. **G2:** the retrograde wire **(white arrow no. 2)** moved to the antegrade subintimal space created with the antegrade balloon through the connection between the antegrade and retrograde subintimal dissection **(white arrow no. 1)**. **G3, G4:** the retrograde wire is passing through the channel created with the antegrade balloon **(white arrow)** and reached to the proximal true lumen **(G4)**. **(H)** After the retrograde wire was led to the guiding catheter, the channel dilation catheter was advanced into the guiding catheter and the retrograde wire was exchanged for a 300-cm Rotablator wire (Boston Scientific, Natick, Massachusetts) **(white arrow)**, which is secured at the right groin for antegrade delivery of the IVUS catheter and the stents. **(I)** Stenting with a 3.5-mm Cypher stent (Cordis, Bridgewater, New Jersey) using the 300-cm Rotablator wire. **(J)** After stenting. **(K)** The channel used for the retrograde access was checked after stenting **(black arrow)**. No channel injury was detected. Abbreviations as in Figure 1.

Table 1. Baseline Characteristics of the Patients (n = 31)

Age, yrs	62.35 ± 9.20 (38–75)
Men (%)	26 (83.8%)
Diabetes mellitus	12 (41%)
Hypertension	24 (76.5%)
Hyperlipidemia	20 (65%)
Previous MI	25 (78%)
Previous CABG	9 (28%)
Vessel disease	
1	4 (7%)
2	11 (35.4%)
3	16 (51.6%)
Previous failed attempts	22 (71%)

Values are mean ± SD (range) or n (%).
CABG = coronary artery bypass graft; MI = myocardial infarction.

successful crossing in 90% of the patients and successful dilation in 81% of the patients. They have reported low complication rates. Again, the same group described the CART technique (20) with high success and low complication rates in a select group of patients.

Sheiban et al. (22) described retrograde approach in 18 cases and reported success rates in 67% of the patients. The

Table 2. Angiographic Characteristics of the Occluded Vessel (n = 31)

CTO vessel	
RCA	25 (80%)
LAD	4 (13%)
LCX	2 (7%)
CTO stump	
Tapering	5 (16%)
Blunt	26 (84%)
Calcification	
None	16 (52%)
Mild	11 (36%)
Moderate	2 (6%)
Severe	2 (6%)
Bridging collaterals	
Present	23 (76%)
Absent	8 (24%)
CTO length	
Range, mm	18–90
Mean ± SD, mm	44.72 ± 21.59
Quantitative coronary analysis	
Lesion length, mm	53.12 ± 20.12
Reference vessel diameter, mm	2.83 ± 1.23
Tortuosity	
None	11 (36%)
Mild	5 (16%)
Moderate	11 (36%)
Severe	4 (12%)

Values are n (%), range, or mean ± SD.
CTO = chronic total occlusion; LAD = left anterior descending artery; LCX = left circumflex artery; RCA = right coronary artery.

Table 3. Collateral Channel, Retrograde Techniques, and Equipment Used During the Procedure (n = 31)

Retrograde channel used	
Septal collateral	
LAD-septal	16 (51.6%)
PDA-septal	3 (10%)
Septal-septal	1 (3%)
Epicardial	
Atrial collateral (LCX)–PL branch	5 (16%)
Diagonal–PDA/PL branch	3 (10%)
PL–PL branch	2 (6%)
SVG	1 (3%)
Collateral channel type	
CC0	3 (9%)
CC1	15 (48%)
CC2	12 (43%)
Wire used to cross retrograde channel	
Fielder FC	24 (77.4%)
Linate	2 (6.4%)
X-Treme	5 (16.2%)
Final wire used inside CTO segment	
Fielder FC	8 (25%)
X-Treme	4 (13%)
Miracle 3	13 (42%)
Miracle 6	1 (3%)
Miracle 12	1 (3%)
Conquest pro 9gm	2 (6%)
Pilot 150	1 (3%)
Retro balloon used inside CTO	
Channel dilator	27 (87.1%)
1.25-mm over-the-wire balloon	4 (12.9%)
Retrograde channel dilation	
Not required	2 (6.4%)
Channel dilator	27 (87.1%)
1.3-mm balloon at 3 atm	2 (6.0%)
Final retrograde concept	
Reverse CART	29 (93.5%)
CART	2 (6.5%)
IVUS guidance	30 (96%)
Snare wire used	4 (13%)
Stent used	29 (93.5%)

Values are n (%).
CART = controlled antegrade and retrograde tracking; IVUS = intravascular ultrasound; PDA = posterior descending artery; PL = posterolateral; other abbreviations as in Table 2.

reasons for failure were mainly inability to cross the small septal collaterals and inability to deliver the balloon or dissection in the CC. Saito (23) reported the results of retrograde attempts in 45 patients, which were performed by a single experienced operator. He has reported the success rate of 69% in this group of patients. The retrograde CC was crossed with the wire in 82% of the patients and the septal collaterals (93%) were used in a majority of the cases. He has reported the minor perforation in 13% of the patients with no long-term sequelae.

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Sianos et al. (24) reported the results of European experience with the retrograde approach for the recanalization of the coronary artery CTOs. They have reported overall success rates of 83.4% and the guidewire crossed the CC successfully in 80.6% of the cases. The collateral perforation rates were reported at 6.9%. We have recently reported similar results from a consecutive series of patients performed by experienced operators and the final success rate was 89% (25). The common reason for failed procedure during retrograde approach in both these studies was inability to cross the collaterals because of severe tortuosity and failure to deliver the balloon through the CC.

The success rates of CTO recanalization has increased from 90% to 95% with the use of retrograde methods and further increased to 97% with the application of IVUS-guided reverse CART in the hands of experienced operators (O.K., E.T., T.S.). With accumulated experience, the operator (O.K.) primarily applies retrograde techniques in 50% to 60% of all CTO cases, mainly difficult or failed antegrade attempts. Recently, reverse CART with IVUS guidance was applied in 60% of the retrograde cases and conventional CART in 5% of cases with retrograde wire crossing in remaining 35% of cases.

Various advanced CTO recanalization techniques including retrograde techniques (CART and reverse CART) could be considered by operators experienced in management of CTO by antegrade approaches. However, there is a learning curve and experience is needed to achieve competence levels.

Retrograde approach offers an alternative approach in the patients with failed antegrade procedure or patients with suitable coronary anatomy. Since its inception a few years back, continuous improvements are seen both in the technology and in the emergence of new devices. With the introduction of the channel dilator, the more tortuous and epicardial channels could be approached without the need for channel dilation with balloon. The channel dilator also provides good backup and easy maneuverability of the retrograde guidewire. This has further increased the utility of the retrograde channel and the success in delivering the guidewire to the CTO segment. Moreover with the reverse CART procedure as described there is minimal need to pass the balloon catheter distal to the CTO site via the CC as subintimal space can be created by the antegrade approach. IVUS guidance has proved to be beneficial in deciding on the size of the antegrade balloon to create optimal subintimal dissection and also direct visualization of the subintimal space and wire crossing.

In our series, the polymer-coated wires have crossed the CC successfully in all the cases. However, in two-thirds of the patients, the stiff guidewires were needed to negotiate through the CTO segment, and they were exchanged for the soft wires at the earliest opportunity. The channel dilator was successfully used in 27 cases and was not needed in 2 patients as the wire crossing through the epicardial CC was easy. In the remaining 2 cases it was difficult to pass the channel dilator because of severe bending inside the CC and the small (1.3 mm) balloon was used to provide backup support. Reverse CART was applied to a majority of the patients, except 2 patients in whom the antegrade balloon could not be delivered to the CTO segment because of severe tortuosity. IVUS was used in all patients except 1, because of nonavailability, to guide the antegrade balloon size. The balloon size used was similar to the vessel diameter to ensure creation of the subintimal dissection, and IVUS examination helps in visualization of the subintimal dissection and the retrograde wire position. Therefore, IVUS guidance can be used for crossing the retrograde wire to the antegrade true lumen via the subintimal connection. In some cases following the crossing of the CTO segment, it was difficult to negotiate the guidewire into the guide catheter. A snare wire was used in these cases to assist the procedure.

With the use of septal collaterals, the collateral perforation could be seen in 5% to 10% of patients. The majority of septal channel perforations are benign and require abandoning that channel and trying other channel. The channel dilator is safer than a balloon and rarely causes CC dissection or perforation, especially in channels with excessive beds and tortuosity. The majority of channel injury patients do not need any further treatment. In some cases, coil embolization may be required. The septal dissections or perforation seen with large series of patients with retrograde recanalization of CTO has shown low complication rates in experienced hands (24,25). The other potential complication is obstruction of inflow into the CC following the introduction of the channel dilator. This can rarely result in reduced visualization of the distal occluded vessel and myocardial ischemia. Therefore, it is important to avoid the dominant and tortuous CC for the access to the distal CTO segment. However, further large-scale studies will be needed to define the safety issues.

The retrograde techniques for CTO recanalization require extensive experience with the usage of different wires, microcatheters, and access to various CCs.

Retrograde approach is an emerging technique and is still evolving. It may be associated with some unexpected complications that are not seen with conventional procedures. The retrograde approach and the current modification should be exclusively performed by highly skilled operators with adequate backup and availability of dedicated equipment, because it requires a combination of different techniques. The success in this series with low complication rates was achieved by a highly skilled and experienced CTO operator.

Advantages of IVUS-guided reverse CART. This modification in the retrograde technique and evolution from CART

technique to reverse CART allows making subintimal connection between the antegrade and retrograde channel confidently under IVUS guidance. This novel modification simplifies the procedure and avoids unidirectional vessel tracking with dedicated CTO wires. This procedure could be performed by bidirectional tracking of soft wires with the help of a channel dilator and IVUS. Also, this reduces the procedure time, as well as reduces cost and radiation exposure. The use of IVUS, compared with conventional retrograde procedures, also reduces the use of contrast medium to nearly one-half.

Limitation of retrograde approach in current stage. This innovative novel technique requires years of experience in the field of treating CTO, including sophisticated wire handling and conventional antegrade techniques. The operators should not be encouraged to adopt the retrograde techniques unless they have reached a certain level of expertise. Despite all recent modifications in the retrograde approach, there is still limited retrograde access in patients with CTO lesions. The atrial, epicardial, septal, and posterolateral channels are present in <60% of all CTO lesions. Predominantly retrograde techniques are dependent on creating subintimal connection and many operators hesitate to create subintimal dissection due to the risk of vessel rupture and spiral dissection. There is also potential of causing myocardial ischemia in the event of collateral injury. Although, this is seen rarely in experienced hands.

Study limitations. First, this case series represents a small number of highly selective cases performed by an experienced operator, therefore the results may not be applicable to less experienced operators. Second, being a retrospective observational study, there are inherent limitations. Third, lack of follow-up beyond hospital stay is an important limitation.

Conclusions

We have described a series of patients with CTO lesions with the application of IVUS-guided reverse CART technique. High procedural success rates could be achieved with this technique by experienced operators.

Reprint requests and correspondence: Dr. Sudhir Rathore, Department of Cardiology, Toyohashi Heart Center, 21-1, Gobudori, Oyama-cho, Toyohashi 441-8530, Japan. E mail: sudhirrathore@hotmail.com.

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Key Words: chronic total occlusion ■ retrograde recanalization ■ intravascular ultrasound ■ controlled antegrade and retrograde tracking ■ collateral channel.