Visualization of Collateral Channels with Coronary Computed Tomography Angiography for the Retrograde Approach in Percutaneous Coronary Intervention for Chronic Total Occlusion

Teppei Sugaya, MD[*,†]; Noriko Oyama-Manabe, MD, PhD[‡]; Takayoshi Yamaguchi, RT[*,§]; Nagara Tamaki, MD, PhD[†]; Shinji Ishimaru, MD, PhD[*]; Hiroaki Okabayashi, MD, PhD[*]; Jungo Furuya, MD[*]; Toshihito Yoshida, MD[*]; Yasumi Igarashi, MD, PhD[*]; Keiichi Igarashi, MD, PhD[*]

Short title: Collateral channels with computed tomography

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[*]Cardiovascular Center, Japan Community Health care Organization Hokkaido Hospital. [†]Department of Nuclear Medicine, Hokkaido University Hospital. [‡]Department of Diagnostic and Interventional Radiology, Hokkaido University Hospital. [§]Graduate School of Medical Science, Kanazawa University.

Address for correspondence: Noriko Oyama-Manabe, MD, PhD; Department of Diagnostic and Interventional Radiology, Hokkaido University Hospital; Kita15, Nishi 7, Kita-ku, Sapporo, JAPAN 060-8638. Office: +81-11-706-5977; Fax +81-11-706-7876; E-mail norikooyama@med.hokudai.ac.jp.

Abstract

Background

There have been no reports about the diagnostic ability of coronary computed tomography angiography (CTA) in evaluating collateral channels used for retrograde chronic total occlusion (CTO) percutaneous coronary intervention (PCI).

Objective

We investigated the diagnostic ability of coronary CTA compared with invasive coronary angiography in correctly detecting collaterals used in retrograde CTO PCI and compared the success rates for wire crossing between CTA visible and invisible collaterals.

Methods

We retrospectively reviewed data from 43 patients (55 collaterals) who underwent coronary CTA and PCI for CTO with the retrograde approach. We compared the ability to visualize collaterals by coronary CTA with that by invasive coronary angiography and the success rates for wire crossing between CTA visible and invisible collaterals.

Results

The sensitivity, specificity, positive predictive value, negative predictive value, and accuracy of coronary CTA for detecting collaterals which used the retrograde approach compared to those which used invasive coronary angiography were 100.0%, 50.0%, 65.9%, 100.0%, and 74.5%, respectively. Guidewire collateral crossing was more successful in CT visible collaterals than in invisible ones (74.1% vs. 46.4%, p = 0.034). There were fewer collateral injuries in CTA visible collaterals compared to invisible ones (11.1% vs. 32.1%, p = 0.041).

Conclusion

Coronary CTA provides good visualization of collaterals used in retrograde CTO PCI compared with that from invasive coronary angiography. A higher success rate with fewer complications was obtained for guidewire crossing in CTA visible collaterals than in invisible ones.

Keywords

Multi-detector row computed tomography, collateral circulation, chronic total occlusion, coronary angiography, retrograde approach, percutaneous coronary intervention, coronary artery disease

Abbreviations list

CTA = computed tomography angiography; CTO = chronic total occlusion; PCI = percutaneous coronary intervention; ECG = electrocardiogram; MACE = major adverse cardiac events; MI = myocardial infarction; TIMI = thrombolysis in myocardial infarction

1. Introduction

A recent report shows that approximately one-fifth of patients undergoing coronary angiography for suspected stable angina have chronic total occlusion (CTO) of the coronary artery (1). There is increasing interest in CTO percutaneous coronary intervention (PCI) with an improved success rate due to recent remarkable technical advances (2-5). In particular, the retrograde approach through collateral channels has improved CTO PCI's success rate (6-8). Successful guidewire collateral crossing is the most important factor in retrograde CTO PCI, leading to procedural success in approximately 90% of cases (9). Appropriate collateral channel selection is therefore crucial to success. The most widely used method to assess collateral channels is invasive coronary angiography (10,11), and the visible and less tortuous collateral channels are known as significant predictors of success for retrograde wire crossing (9). Among collateral channels, septal collaterals are most frequently used in the retrograde approach and are safer to use than epicardial collaterals (12). Unsuccessful wire collateral crossing were seen occurring in 17.7–26.8% of patients who underwent retrograde CTO PCI, despite it being performed by experienced CTO operators

(6,8,9,13). Furthermore, some fatal collateral complications related to the retrograde approach, including perforation and septum hematoma, were reported even though the collaterals were carefully chosen with invasive coronary angiography or selective angiography by microcatheter (14,15).

Recently, coronary computed tomography angiography (CTA) has been used as a feasible noninvasive method of diagnosing coronary artery disease (16-18). Moreover, some small vessels such as collaterals can now be visualized due to improvements in spatial resolution (19,20). However, there have been no reports thus far about the diagnostic accuracy of coronary CTA in evaluating septal and epicardial collaterals used in retrograde CTO PCI.

The purpose of this study was to assess retrospectively the diagnostic ability of coronary CTA compared with invasive coronary angiography in correctly detecting collaterals used in retrograde CTO PCI and to compare the success rates for wire crossing between CT visible and invisible collaterals.

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2. Material and Methods

2.1. Study Population

With approval from our hospital's institutional review board, we retrospectively reviewed data from a total of 134 patients who underwent PCI for CTO at a single center (Japan Community Health care Organization, Hokkaido Hospital, Sapporo, Japan) between June 2010 and March 2013. CTO was defined as a lesion showing thrombolysis in myocardial infarctions (TIMI) of grade 0 for more than 3 months. Occlusion duration was estimated based on a history of angina, previous myocardial infarction (MI) in the same territory, or proven by previous invasive coronary angiography or coronary CTA. The retrograde approach was attempted in 75 patients; of which 49 who underwent coronary CTA before PCI within 5 weeks were enrolled in our study.

2.2. Angiographic Assessment of collaterals

Diagnostic coronary angiography was performed using an INNOVA 2000 (GE Heathcare, Milwaukee, Wisconsin) or Aulla XPER FD-10 (Philips Medical Systems, Best, the Netherlands) in all patients before CTO PCI. Collaterals by coronary angiography were categorized into two groups, as modified from previous reports (10): invisible collateral with coronary angiography, no continuous connection between donor and recipient vessel; or visible collateral with coronary angiography, continuous thread-like or small branch-like connections were visualized. Two experienced observers blinded to clinical history evaluated collaterals by coronary angiography independently. In cases of disagreement, consensus readings were performed.

2.3. CTA acquisition and data analysis

Coronary CTA was performed using a 64-slice computed tomography (CT) scanner (Light Speed VCT, GE Healthcare, Milwaukee, Wisconsin). Patients with irregular heart rates or heart rates >60 beats/min received 2–20 mg of propranolol hydrochloride intravenously. For heart rates <60 beats/min despite injection of propranolol hydrochloride, the step and shoot technique (Snapshot Pulse, GE Healthcare, Milwaukee, Wisconsin) was applied. If the heart rate remained irregular or >60 beats/min, the helical technique with low helical pitch (cardiac helical) was used. Coronary images were acquired with the following parameters: slice collimation, 64 × 0.625 mm; gantry rotation time, 0.35 ms; table feed, 7.2–8.2 mm/rotation; tube energy, 120 kV; and tube current, 600–800 mA. For the screening of coronary artery disease, 280 mgI/kg of nonionic contrast material (350 mgI/mL of iohexol, Omnipaque-350, Daiichi-Sankyo, Tokyo, Japan) was injected at a fixed duration of 12 s in 21 patients. When the existence of CTO was known before coronary CTA, 320–350 mgI/kg of nonionic contrast material was injected at a fixed duration of 12 s in 28 patients. Mean contrast volume was 61.4±9.9 ml. Contrast administration was followed by 0.9% saline solution at a fixed duration of 7 s at the same flow rate as the contrast material (test-bolus tracking method) (21). Raw CT data were reconstructed using algorithms optimized for retrospective electrocardiogram (ECG)-gated segment reconstruction. CT image data were transferred to a computer workstation for post-processing (Ziostation 2, Ziosoft Inc., Tokyo, Japan). Volume-rendered images, curved multiplanar reformations, maximum intensity projections, and cross-sectional images were reconstructed. Image quality of each coronary artery was visually assessed and divided into four groups: 3, all main coronary vessels could be clearly evaluated; 2, all main coronary vessels were acceptable for evaluation; 1, one main coronary vessel was difficult to evaluate due to motion artifact; or 0, more than two main vessels had motion artifact. The visibility grade of collaterals with CT was defined as that defined with invasive coronary angiography: invisible collateral with CT, no continuous connection between donor and recipient vessel (**Fig. 1A**); visible collateral with CT, collateral is seen as a tiny connection as a completely continuous, small branch-like connection (**Fig. 1B**). Two experienced observers independently evaluated image quality and collateral visibility. In cases of disagreement, consensus readings were performed.

2.4. Retrograde Procedure

The retrograde approach was defined as introducing the guidewire from the donor vessel into collaterals, which might be connected to the distal end of the CTO. The choice of collaterals and guidewire was completely at the operator's discretion. First, a hydrophilic coated guidewire or a tapered polymer jacket guidewire was inserted into the target collateral with the aid of a microcatheter. After the successful crossing of the guidewire into the CTO's distal end, either retrograde wire crossing, the kissing wire technique, or the reverse controlled antegrade and retrograde subintimal tracking technique was attempted to cross the wire through the CTO.

2.5. Statistical analysis

Continuous data are presented as mean ± SD and their differences were compared using the Student *t*-test. Discrete variables are expressed as counts and percentages, with their differences assessed by Fischer exact tests and χ^2 tests. The sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of coronary CTA were computed for visualization of collaterals in comparison with invasive coronary angiography. All statistical tests were two-tailed and significance was set at $p < 0.05$. Analyses were performed using JMP Pro, version 11.0.0 (SAS Institute, Cary, NC).

3. Results

3.1. Patient and Procedural Characteristics

We excluded 6 patients with coronary CTA image quality scores of 0 or 1 due to motion artifacts or incomplete breath holding. As a result, our study ultimately included 43 patients. Patient characteristics are summarized in **Table 1**. Successful guidewire collateral crossing was accomplished in 33 patients (76.7%). Of them, the final retrograde recanalization of CTO was successful in 28 patients (84.8%). In regards to major adverse cardiac events (9), there were no in-hospital mortalities; however, non-Q-wave MI was noted in one patient, and heart failure requiring urgent hospital treatment was noted in one patient. These patients were managed medically, recovered, and were discharged.

3.2. Collateral characteristics

The retrograde approach was attempted with wires in 55 collaterals from 43 patients. Septal and epicardial collateral properties are shown in **Table 2**. The most commonly used collateral was a septal branch, especially from the LAD to branches of the posterior descending artery of occluded RCA in 34 cases (61.8%). **Table 3** summarizes the visualization of all 55 collaterals by invasive coronary angiography and coronary CTA. The sensitivity, specificity, PPV, NPV, and accuracy of coronary CTA for detecting the collaterals, assuming invasive coronary angiography as the gold standard, were 100.0%, 50.0%, 65.9%, 100.0%, and 74.5%, respectively. The accuracy of coronary CTA for epicardial collaterals was higher than that for septal collaterals: the sensitivity, specificity, PPV, NPV, and accuracy of coronary CTA in the former were 100.0%, 66.7%, 87.5%, 100.0%, and 90.0%, respectively, whereas in the latter these values were 100.0%, 48.0%, 60.6%, 100.0%, and 71.1%, respectively.

3.3. Success Rates for Guidewire Crossing into Visible and Invisible CT-collaterals

Success rate comparisons for the guidewire collateral crossing between visible and invisible collaterals with CT are shown in **Figure 2**. Success rate was significantly higher for visible collaterals than for invisible collaterals with CT (74.1% vs. 46.4%, $p = 0.034$). Regarding septal and epicardial collaterals, there was a trend for greater success for visible than invisible collaterals with CT. Representative CTO PCI cases with septal and epicardial collaterals are shown in **Figures 3** and **4**, respectively.

3.4. *Collateral Injuries*

There were fewer collateral injuries in the visible collaterals than the invisible collaterals with CT (11.1% (3/27) vs. 32.1% (9/28), p = 0.041). Septal collateral perforations were observed in five cases in the invisible collaterals and in one case in the visible collaterals. Coil embolization was performed in one patient, where immediate hemostasis was achieved without cardiac tamponade. The rest were managed conservatively with no hemodynamic compromise. Arteriovenous or coronary-ventricular fistulae were developed in two cases in the invisible collaterals and one case in the visible collateral. Aneurysmal change was detected by angiography in two cases in the invisible collaterals and one case in the collateral. These collateral channel injuries required no further treatment.

4. Discussion

The major findings of this study are as follows: First, coronary CTA compared with invasive coronary angiography provided good visualization of collaterals used in retrograde CTO PCI, reaching an accuracy of 74.5%. The accuracy of coronary CTA for epicardial collaterals was higher than that for septal collaterals. Second, guidewire collateral crossing had a higher success rate in visible than in invisible collaterals with coronary CTA. Finally, during retrograde CTO PCI, there were fewer collateral complications in visible than in invisible collaterals with CT. This appears to be the first report investigating the diagnostic ability of coronary CTA to detect collaterals used in retrograde CTO PCI compared with invasive coronary angiography.

The existence of collaterals in ischemic heart disease determines patient prognosis (22-24). Severe tortuosity of the collateral and invisibility of the connection in invasive coronary angiography are independent predictors of procedural failure in the retrograde approach in CTO PCI (9). Despite its clinical importance, noninvasive evaluation of collaterals has been limited. Coronary CTA is a promising noninvasive method for detecting and excluding obstructive coronary artery stenosis and has begun to replace invasive coronary angiography in some clinical scenarios (25-27). A previous study with 64-row detector CT reported that coronary CTA could visualize relatively large collaterals, such as epicardial collaterals, as Rentrop grade 2 or 3, while there remain some difficulties in evaluating smaller collaterals, primarily due to limited spatial and temporal resolution (19). Coronary CTA may visualize more physiological conditions of collaterals than invasive coronary angiography, in which the coronary artery is wedged by a catheter. In the present study, we investigated the ability of coronary CTA compared with invasive coronary angiography to visualize both septal and epicardial collaterals used in retrograde CTO PCI. Coronary CTA detected collaterals used in retrograde CTO PCI with an accuracy of 74.5%. The specificity and PPV for epicardial collaterals were higher than those for septal collaterals, and the difference in visualization between septal and epicardial channels may depend on several factors. Epicardial collaterals are larger than septal collaterals and are located in adipose tissue, which provides a better visual contrast (20). On the other hand, septal collaterals are generally smaller and run through the myocardium, which is susceptible to cardiac phase and timing of contrast filling (28). Image quality of collaterals also depends on the timing of the scan after administration of contrast media. If the scan occurs too early, collateral enhancement would be insufficient, and if it occurs too late, the contrast between the septal myocardium and collaterals would be lost. We used the test-bolus tracking method, which is an injection technique that continuously performs the test bolus injection and the main bolus injection (21). This method facilitates acquisition of the best scan timing and improves image quality, including that of collaterals. Moreover, in this study, higher dose (320–350 mgI/kg) nonionic contrast material (350 mgI/mL) was used in 25 cases (58.1%) with known existence of CTO before coronary CTA, which should provide enough contrast media for collateral visualization.

The higher success rate for collateral wire crossing through visible, in comparison with invisible, collaterals might be related to collateral and wire sizes, as well as spatial CT resolution, as previously reported (23). Spatial CT resolution was approximately 0.6 mm (29). On the other hand, the diameter of the wire tip used for the retrograde approach was 0.35 mm. Therefore, visible epicardial collaterals with CT should be large enough to be crossed easily by a wire. Moreover, the diameter of the tip of Corsair (Asahi Intec, Nagoya, Japan), which is the most frequently used microcatheter in contemporary retrograde CTO PCI, is 0.42 mm (30), smaller than visible collaterals and hence can be advanced easily into the visible collaterals. On the other hand, septal collaterals tend to be tortuous and smaller compared to epicardial collaterals (10). A previous study reported that the key morphology contributing to successful wire crossing was not the vessel’s tortuosity but its size (12). Since tortuous collaterals can be straightened by the microcatheter, tortuosity itself might not be a problem. Success in wire crossing might depend on the size of the vessel, which is large enough for microcatheter use (8). Visible collaterals with CT may be large enough for successful wire crossing.

In a multicenter registry in the United States, major collateral injury, including perforation and hematoma requiring pericardiocentesis or surgery, occurred in 1.3% of collaterals using the retrograde approach (6). The latest study from a Japanese multicenter registry of retrograde PCI for CTO reported collateral injury in 8.4% of patients and major collateral injury in 1.4% (8). In our study, there was only one case (1.8%) out of the 55 with collateral injury requiring coil embolization. Minor injury, needing no further treatment, was detected by angiography in 12 (21.8%) of 55 collaterals. The rate of injury in visible collaterals was significantly lower than that in invisible collaterals with CT.

Retrograde CTO PCI remains a challenging procedure associated with increased risks of significant complications and the operator's experience level has a significant influence on the success rate (31). Accomplishing retrograde guidewire collateral crossing is crucial to procedural success, therefore appropriate collateral channel selection is extremely important (13). In addition to information about the presence and location of collaterals, coronary CTA provides three-dimensional morphological information on collaterals and the best intra-procedural projection. If several collaterals are visible in invasive coronary angiography, pre-procedural coronary CTA may facilitate the selection of the best one. Coronary CTA could be a useful tool to optimize PCI strategy for CTO and reduce contrast volume and time spent on fluoroscopy.

Furthermore, Coronary CTA might become a method to simplify and standardize retrograde PCI procedures.

There are some limitations to our study. First, it is retrospective, and we analyzed only the collateral channels actually used in retrograde PCI. Unused collaterals with the potential for use in the retrograde approach were not evaluated. Further prospective investigation for comparison of successful PCI rates between visible and invisible collaterals would be more clinically relevant. However, we retrospectively tried to reveal the coronary CTA visibility of collaterals used in retrograde PCI in comparison with CAG as a preliminary study. Second, the number of cases was small and all cases were from a single center. Third, the results of this study could have been influenced by selection criteria and operator experience. Fourth, contrast media volume was different between patients with known vs. unknown CTO. Fifth, we used a specific ”test-bolus tracking method” (21) to achieve stable coronary enhancement, as we aimed to reveal the coronary CTA visibility of collaterals. Finally, this study used the widely available 64-row detector CT, which has a limitation of lower spatial resolution. With a >128-row detector CT, visualization of collaterals with CT might be improved.

5. Conclusions

The collateral channels used in the retrograde approach were well visualized with coronary CTA with high accuracy compared to invasive coronary angiography. A higher success rate in guidewire collateral crossing with fewer complications was obtained in visible collaterals than in invisible ones with CT.

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Figure Legends

Figure 1. Visibility grade of collateral channels in a curved multiplanar reformation of coronary CTA

(A) Invisible collateral with CT: A case of CTO at the proximal RCA with coronary CTA. There is no continuous connection between donor and recipient vessel.

(B) Visible collateral with CT: A case of CTO at the mid-LAD. There is a continuous septal collateral (arrows), with the appearance of a small branch, from the RCA to the mid-LAD.

CTA, computed tomography angiography; CTO, chronic total occlusion; LAD, left anterior descending artery; RCA, right coronary artery.

Figure 2. Success rate for guidewire collateral crossing

The success rate for guidewire collateral crossing in the visible collaterals was significantly higher compared to the invisible collaterals with CT.

Figure 3. RCA CTO case with septal collateral channel

(A) CTO (arrows) of the RCA was shown in curved multiplanar reformat (CPR) image with coronary CTA.

(B) A continuous connection of septal collateral channel (arrows) from the LAD was seen in invasive coronary angiography.

(C) CPR image with coronary CTA showed the same septal collateral channel (arrows) as invasive coronary angiography.

(D) The three dimensional CT image emphasized the septal collateral (green) to CTO lesion (light blue).

(E) The retrograde wire was successfully crossed through the septal collateral channel.

(F) Finally, CTO was recanalized by ballooning and stenting.

Figure 4. RCA CTO case with epicardial collateral

(A) CTO (arrow) of the distal RCA was shown in CPR image with coronary CTA.

(B) A continuous connection of epicardial collateral channel (arrows) from the left circumflex artery was seen with invasive coronary angiography.

(C) CPR image with coronary CTA showed the same continuous epicardial collateral channel as invasive coronary angiography.

(D) The three dimensional CT image emphasized epicardial collateral channel (green) to CTO lesion (light blue).

(E) The retrograde wire was successfully crossed through the epicardial collateral channel.

(F) Finally, CTO was recanalized by ballooning and stenting.

Table 1. Patient Characteristics

	All n = 43	Collateral wire cross n = 33	Collateral wire no cross n = 10	P
Age (years)	65.4 ± 9.4	65.2 ± 8.9	66.3 ± 11.3	0.753
Male sex	36 (83.7%)	27 (81.8%)	9 (90.0%)	0.377
Diabetes	26 (60.5%)	20 (60.6%)	6 (60.0%)	0.539
Hypertension	35 (81.4%)	25 (75.8%)	10 (100.0%)	0.973
Dyslipidemia	33 (76.7%)	23 (69.7%)	10 (100.0%)	0.084
Smoking	23 (53.5%)	18 (54.5%)	5 (50.0%)	0.801
Dialysis	5 (11.6%)	5 (15.2%)	0 (0.0%)	0.190
Body height (m)	1.63 ± 0.1	1.63 ± 0.1	1.62 ± 0.1	0.722

Body weight (kg)	67.2 ± 12.9	66.4 ± 12.6	70.1 ± 13.6	0.377
Body mass index (kg/m^2)	25.2 ± 3.7	24.7 ± 3.3	26.8 ± 4.7	0.133
Prior attempt at CTO	18 (41.9%)	13 (39.4%)	5 (50.0%)	0.551
History of CABG	3 (7.0%)	3 (9.1%)	0 (0.0%)	0.323
CTO vessel				
LAD	9 (20.9%)	7 (21.2%)	2 (20.0%)	
LCX	4 (9.3%)	2 (6.1%)	2 (20.0%)	
RCA	30 (69.8%)	24 (72.7%)	6 (60.0%)	
J-CTO score				
0	5 (11.6%)	4 (12.1%)	1 (10.0%)	

1	11 (25.6%)	7 (21.2%)	4 (40.0%)	
2	7 (16.3%)	5 (15.6%)	2 (20.0%)	
3	12 (27.9%)	10 (30.3%)	2 (20.0%)	
4	8 (18.6%)	7 (21.2%)	1 (10.0%)	
5	0 (0.0%)	0 (0.0%)	0 (0.0%)	
Image quality of coronary CTA	2.5 ± 0.5	2.4 ± 0.5	2.8 ± 0.4	0.057
Estimated radiation dose (mSv)	24.7 ± 7.2	25.2 ± 7.3	23.0 ± 7.1	0.400
Duration between coronary CTA and PCI (days)	8 (range, 2-28)	8 (range, 2-34)	6 (range, 2-28)	0.556

Data are presented as mean ± standard deviation or as n (%).

CABG, coronary artery bypass graft; CTA, computed tomography angiography; CTO, chronic total occlusion; LAD, left anterior descending artery; LCX, left circumflex artery; PCI, percutaneous coronary intervention; RCA, right coronary artery.

Table 2. Collateral Characteristics

CTO vessel	Channel used	All collateral channels (n = 55)
	Septal channel	45 (81.8%)
RCA	LAD – septal branch – RCA	34
LAD	LAD – septal branch – LAD	4
LAD	RCA – septal branch – LAD	7
	Epicardial channel	10 (18.2%)
RCA	LCX LA branch – RCA PL	5
LAD	RCA conus branch – LAD	1
LCX	LCX LA branch – distal LCX	1
LCX	Diagonal branch – LCX	1
LCX	Distal LAD – LCX	1
LCX	RCA PL branch – LCX	1

Data are presented as n (%).

LAD, left anterior descending artery; LCX, left circumflex artery; PL = posterior lateral branch; RCA, right coronary artery.

Table 3. Visualization of collaterals with invasive coronary angiography and coronary CTA

		Coronary CTA	
	All collaterals (n = 55)	Invisible collaterals (n = 28)	Visible collaterals (n = 27)
Invasive coronary angiography	Invisible collaterals	14	0
	Visible collaterals	14	27

		Coronary CTA	
	Septal collaterals (n = 45)	Invisible collaterals (n = 25)	Visible collaterals (n = 20)
Invasive coronary angiography	Invisible collaterals	12	0
	Visible collaterals	13	20

Epicardial collaterals (n = 10)		Invisible collaterals (n = 3)	Visible collaterals (n = 7)
Invasive coronary angiography	Invisible collaterals	2	0
	Visible collaterals	1	7

Data are presented as n.

CTA, computed tomography angiography.

Fig.1

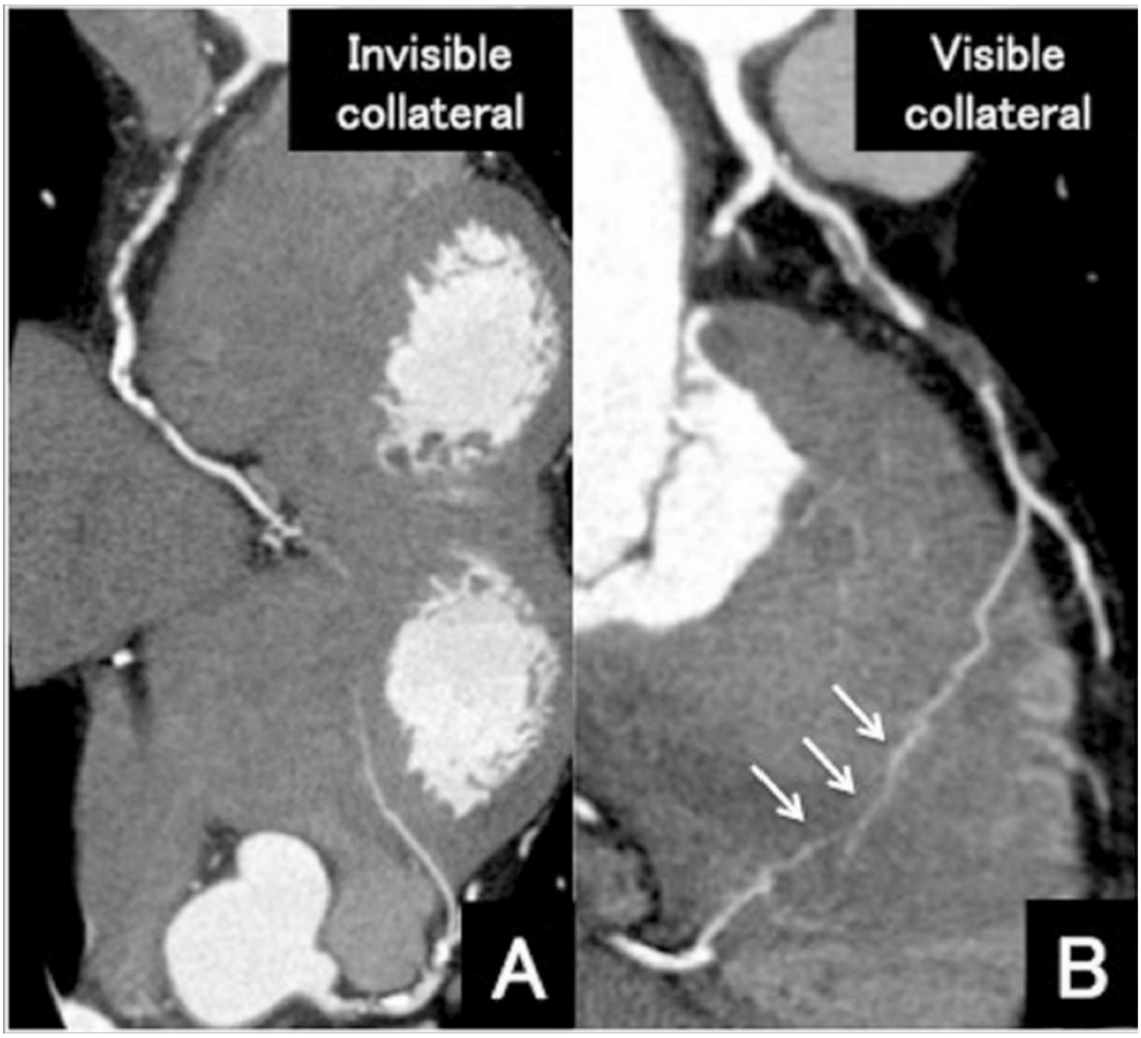

Fig.2

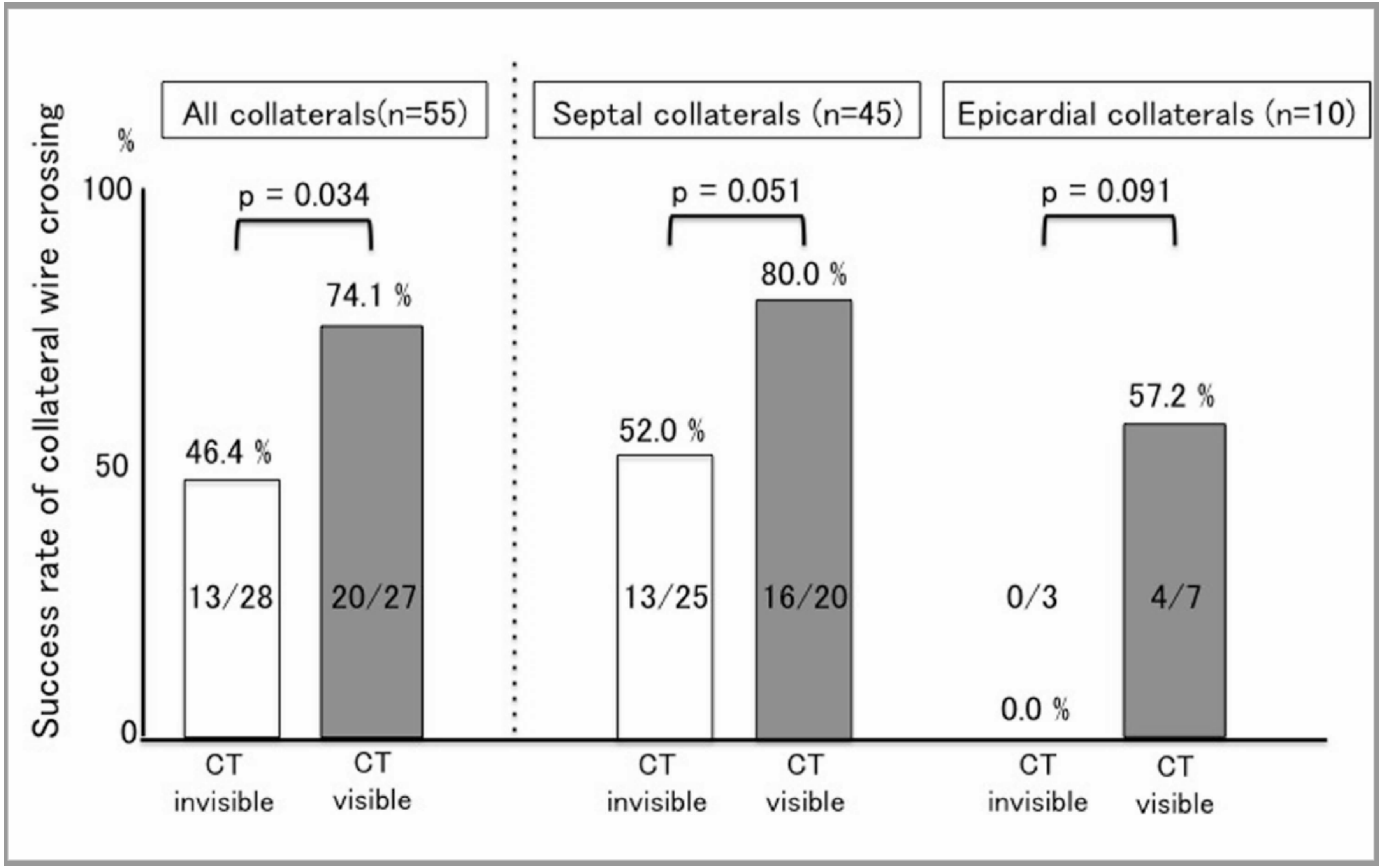
All collaterals(n=55)
Septal collaterals (n=45)
Epicardial collaterals (n=10)
Success rate of collateral wire crossing
%
100
50
0
p = 0.034
p = 0.051
p = 0.091
46.4 %
74.1 %
52.0 %
80.0 %
0.0 %
57.2 %
13/28
20/27
13/25
16/20
0/3
4/7
CT invisible
CT visible
CT invisible
CT visible
CT invisible
CT visible

Fig.3

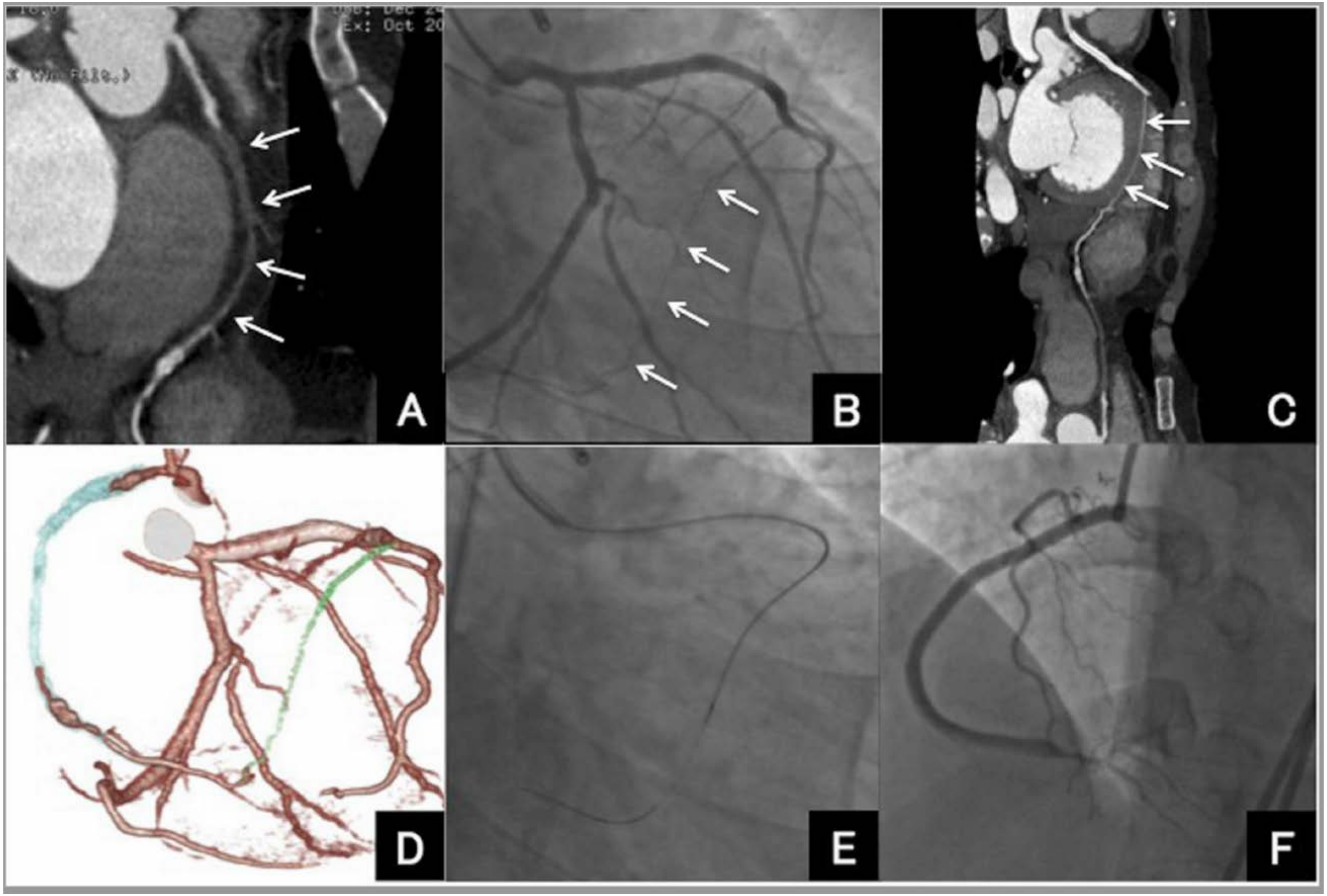

Fig.4