Comparison of coronary angiography-assisted and computed coronary tomography angiography-assisted recanalisation of coronary chronic total occlusion

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ABSTRACT

Background Computed coronary tomography angiography (CCTA) provides an alternative to coronary angiography (CAG) and a complementary way of imaging.

Objective To determine whether CT assistance might help increase the recanalisation rate of coronary chronic total occlusion (CTO).

Method Two experienced physicians took part in the study—one specialised in both CCTA and percutaneous coronary intervention (PCI), and the other had PCI experience only and no knowledge of CCTA. Consecutive patients were enrolled if CTO was diagnosed by CAG or by CCTA. The images were analysed on a dedicated work station which examined the length and characteristics of the occlusion, the calibre of the artery, the best projection for precision guidewire penetration, the use of a side branch and calcification for landmarking and selection of most suitable guidewires. Patients underwent CAG-guided PCI or CCTA-assisted PCI. The main end point was the recanalisation rate. Secondary end points included the time for successful passage of the guidewire, fluoroscopy time, and contrast, guidewire and stent consumption.

Results Thirty-six patients underwent CAG and 44 CCTA. The clinical characteristics and laboratory data of the two groups were similar ($p>0.05$). The patients in the CCTA group had more complex disease than those in the CAG group as shown by the J-CTO score (Multicenter CTO Registry of Japan) ($p<0.05$). Recanalisation was possible in 75.8% of the CAG group and 72.1% of the CCTA group. However, no statistical significance was found, $p>0.05$. In five of seven patients who had undergone unsuccessful PCI previously the procedure was successful at the second attempt when CCTA-assisted PCI was used. The patients were divided into those for whom the procedure was a failure or a success. The J-CTO score was an independent predictor of failure (OR=0.290, 95% CI 0.158 to 0.533).

Conclusion CTO with favourable characteristics does not need CCTA guidance, but CCTA can be used to recanalise CTO with unfavourable characteristics when the procedure has previously failed.
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from centre to centre according to the CTO registry.³ The success rate in Dr Han' group is around 90%.⁴ The success rate for Japanese operators is also 90% owing to the development of a newer technique.⁵ However, few cardiologists would achieve such a high level of success. Success mainly depends on whether the occlusion has favourable characteristics or not. The chance of success for a favourable occlusion might be as high as 90% while for an unfavourable occlusion it might be <50%. For the unfavourable occlusion, the occlusion length and characteristics, the side branch, the calibre of the vessels and the tortuosity of the artery may all contribute to failure, as may the way of manipulating the guidewire to the target vessel. Coronary tomography angiography (CCTA) provides an alternative and complementary imaging method.⁶ The occlusion can be visualised by soft-tissue CT imaging. The length and calibre of the artery and its three-dimensional orientation may help to guide the PCI. However, it is not known whether CT assistance might help to increase the recanalisation rate.

PATIENTS AND METHODS

Patient selection

Consecutive patients entered the trial if they met the following criteria: age 30–80 years; CTO diagnosed by either coronary angiography (CAG) or CCTA; gave consent for percutaneous coronary intervention (PCI). The exclusion criteria included acute myocardial infarction, late-stage renal failure, chronic obstructive pulmonary diseases, pregnancy, severe heart failure, ejection fraction <35%, extensive calcification by CCTA, allergy to contrast dye.

Study protocol

The study protocol was approved by the ethics committee of our institution. A nurse explained the risks and benefits of the procedure to all study patients. All patients gave written informed consent for CCTA and CAG as a part of their participation in the study. The study was registered in ACTRN12611000368932. The patients with CTO identified by CCTA or CAG were divided into two groups. For the group receiving CCTA-assisted PCI, the operator was experienced in both CCTA and PCI. The following methods were used to facilitate the recanalisation: estimation of the length of the occlusion, determination of the characteristics of the occlusion and the best projection for visualising the entry point for the precision puncture, and use of a sequential guidewire technique (precision

INTRODUCTION

The successful recanalisation of chronic total occlusion (CTO) relieves symptomatic ischaemia and angina, prolongs survival and improves left ventricular function.¹ Unsuccessful recanalisation results in poor long-term survival.² The success rate varies

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Table 1 Clinical characteristics of the patients

Characteristics	CAG		CCTA		p Value
Male	28/36	(77.8%)	35/45	(77.8%)	1.000
Wall motion abnormality	9/32	(28.1%)	9/34	(26.5%)	0.880
Stable angina	10/36	(27.8%)	10/45	(22.2%)	0.565
Unstable angina	22/36	(61.1%)	28/45	(62.2%)	0.919
Acute myocardial infarction	4/36	(11.1%)	4/45	(8.9%)	1.000
Old myocardial infarction	12/36	(33.3%)	11/45	(24.4%)	0.378
PCI history	10/36	(27.8%)	8/45	(17.8%)	0.282
In-stent total occlusion	3/36	(8.3%)	2/45	(4.4%)	0.651
Statin therapy	11/36	(30.6%)	24/45	(53.3%)	0.040
Diabetes mellitus	12/36	(33.3%)	9/44	(20.5%)	0.193
Renal insufficiency	3/36	(8.3%)	0/43	(0.0%)	0.090
Family history	16/23	(69.6%)	16/31	(51.6%)	0.184
Heart function (NYHA)	44.18*	1590.5†	38.46*	1730.5†	0.026
Hypertension	43.43*	1563.5†	39.06*	1757.5†	0.377
Alcoholic	37.10*	1113.0†	33.38*	1302.0†	0.414
Smoking	37.91*	1099.5†	32.89*	1315.5†	0.202

*Mean rank.

†Rank sum (heart function, hypertension, drink and smoke history were ordinal and analysed by non-parametric tests).

CAG, coronary angiography; CCTA, coronary tomography angiography; NYHA, New York Heart Association; PCI, percutaneous coronary intervention.

puncture, stiff wire for direction and penetration, fast drill, change of soft wire after successful penetration, use of side branch and calcification for location). For the group receiving CAG-guided PCI, the operator had no knowledge of CCTA and was blinded to the CCTA results. The PCI was performed in a conventional way.

Outcome measures

The main end point was the recanalisation rate. Secondary end points included the time for successful passage of the wire, fluoroscopy time, contrast, guidewire and stent consumption, and level of complications during the procedure. The cause of failure was analysed.

Coronary tomography angiography

All patients fasted for 4 h before each examination. A General Electric (GE) Discovery PET/CT 64-slice CT was used and metoprolol (oral 25–50 mg, or intravenous injection 5–10 mg) was administered for β blockade. Patients were excluded if they had a contraindication to β blockers; a known allergic reaction to iodinated contrast media; an inability to follow breath-hold commands; renal insufficiency (serum creatinine >1.5 mg/dL);

Table 2 Chronic total occlusion (CTO) characteristics

CTO characteristics	CAG		CCTA		p Value
Calcification	8/36	(22.2%)	18/45	(40.0%)	0.0886
Bending $\geq 45^\circ$	6/36	(16.7%)	18/45	(40.0%)	0.0223
Length of occlusion ≥ 20 mm	14/34	(41.2%)	18/44	(40.9%)	0.9810
Retry	1/35	(2.9%)	5/45	(11.1%)	0.1644
Stent	4/36	(11.1%)	3/45	(6.7%)	0.4793
Side branch	20/36	(55.6%)	26/45	(57.8%)	0.8410
J-CTO score	36	1.11 $\pm$ 1.01	45	1.78 $\pm$ 1.31	0.0116
SYNTAX score	36	21.33 $\pm$ 7.63	45	23.84 $\pm$ 11.83	0.2518

CAG, coronary angiography; CCTA, coronary tomography angiography.

Table 3 Device used

Device	CAG		CCTA		p Value
Guide wire	31	1.26 $\pm$ 0.63	41	1.34 $\pm$ 0.76	0.6225
Balloon	31	2.61 $\pm$ 1.69	41	3.37 $\pm$ 1.81	0.0766
Angiographic catheter	31	1.29 $\pm$ 0.78	41	1.44 $\pm$ 0.67	0.3898
Guiding catheter	31	1.48 $\pm$ 0.68	41	1.73 $\pm$ 0.84	0.1821
Micro-catheter	31	0.45 $\pm$ 0.57	41	0.54 $\pm$ 0.64	0.5589
Stent	31	1.81 $\pm$ 1.28	41	2.00 $\pm$ 1.36	0.5413
Radiation time (s)	33	2065 $\pm$ 1203	44	2307 $\pm$ 1376	0.4221
Contrast (mL)	33	213.94 $\pm$ 79.92	42	220.00 $\pm$ 79.76	0.7451

CAG, coronary angiography; CCTA, coronary tomography angiography.

hyperthyroidism; or advanced heart failure (New York Heart Association grade III–IV). Patients received a single dose of 0.5 mg nitroglycerin sublingually 2 min before CT. For CCTA, 80 mL of iodixanol (iopromide 370, 370 mg/mL, Schering-Plough Healthcare, Guangzhou, China) at a rate of 5 mL/s followed by 50 mL intravenous saline injection via a 21-gauge catheter were given. Bolus tracking was performed in the region of interest in the ascending aorta. Image acquisition was carried out as follows: 0.625 mm slice thickness, z coverage 40 mm, heart-rate-adapted pitch of 0.18–0.26, gantry rotation time 350 ms, tube voltage 120 kV, effective tube current adapted to body mass index (280–750 mA) and ECG-adapted tube modulation. CT datasets were retrospectively reconstructed in mid-diastolic to end-diastolic and additional phases if needed for optimal coronary artery visualisation. Data were transferred to an offline workstation (GE Healthcare) and assessed using the software package for vessel or plaque analysis. Software analysis is based on multiplanar reconstructions and maximum intensity projections. Images are displayed along, and orthogonal to, the centre line of the coronary arteries. For additional orientation, thin-slab maximum intensity projections and three-dimensional volume renderings were used.

Coronary angiography

CAG was performed by the Philips and GE Innova 3100 angiography system. CAG was performed through the femoral or radial artery according to physician preference. The films were read by two cardiologists and the Syntax score was calculated to evaluate both degree and extent of disease.

Statistical analysis

Statistical analysis was performed with software (SPSS V.17.0). A p value of <0.05 was considered to be statistically significant. Quantitative variables were expressed as the mean $\pm$ SD and categorical variables as frequencies or percentages. A Pearson χ^2 test was used to measure the difference.

Table 4 Recanalisation

	CAG		CCTA		p Value
Revascularisation	28/36	(77.8%)	33/45	(73.3%)	0.6448
Wire-balloon time	36	15.1 $\pm$ 18.6	45	11.3 $\pm$ 17.9	0.3508

CAG, coronary angiography; CCTA, coronary tomography angiography.

Figure 1 Characteristic left anterior descending artery lesions on coronary tomography angiography.

RESULTS

Baseline clinical characteristics

The baseline characteristics were similar in both groups, although the patients in CCTA group received more lipid-lowering agents (table 1).

CTO characteristics and success rate

There was no difference in the CTO characteristics except the J-CTO score. The J-CTO score was higher in CCTA ($p < 0.05$) (table 2).

Device used

There was no difference in the device used, $p > 0.05$ (table 3).

Recanalisation rate

The recanalisation rate was 77.8% in the CAG group and 73.3% in the CCTA group. The difference was not significant ($p > 0.05$) (table 4). There was also no difference in wire to balloon time which was a measure of the speed of recanalisation.

An extremely difficult CTO was successful recanalised.

Figure 2 Coronary angiography of the left coronary artery before and after percutaneous coronary intervention. On left anterior oblique (LAO) 42°, cranial (CRA) 28° (A) and LAO 45°, caudal (CAU) 30° (B) proximal views the left anterior descending artery (LAD) was totally occluded with a blunt stump and side branches coming off the D1. The LAD was revascularised successfully and was stented by three stents. On the right anterior oblique (RAO) 11°, CRA 40° view a long stent extending into the left main coronary artery was visualised (C). On LAO 45°, CAU 31° views the procedure was completed with satisfactory results (D).

Figure 3 The wiring guided by coronary tomography angiography and coronary angiography (CAG). The wire first enters the septal branch (A). The wire was in the false lumen as judged by the significant distance between the wire and true lumen. Guided by repeated CAG the tip of the guidewire was approaching the true lumen. The orientation of another guidewire was adjusted gradually towards the true lumen (C–F). The wire reached the distal lumen without much friction, indicating that it was in the true lumen (G). Balloon dilatation was performed (H).

As could be seen by CCTA the left anterior descending artery (LAD) was totally occluded (figure 1). Several features suggested unfavourable anatomy for recanalisation of the CTO, including the long occlusion with length about 40 mm; side branch at the occlusion; moderate calcification and small exit artery. With CAG a side branch at the occlusion was clearly seen (figure 2). During the procedure, however, there was no difficulty in precision puncture of the LAD by stiff wire (figure 3). Keeping the CT image in mind we slowly advanced the wire keeping it as central as possible. The wire first accidentally entered the septal branch and was left there as a landmark. A second wire was inserted but kept entering the false lumen. We then redirected the wire toward the true lumen by a conquest wire.

PCI repeated under the guidance of CCTA

Of the 36 patients in the CAG group, seven had previously undergone unsuccessful PCI. Guided by CCTA, PCI was successful in five of the seven at the second attempt. In the CCTA group seven patients had previously undergone unsuccessful

PCI. Before the second attempt the CCTA and CAG images were carefully reviewed to determine the causes of failure. Five of seven patients were successfully recanalised when PCI was repeated (figure 4). The main reasons for the failure are listed in table 5.

In case 1 no stump was discernable. The operator considered that PCI was not possible because there was no stump puncture. Reconstruction of the CCTA showed the location of the stump, and blind puncture of the stump resulted in recanalisation. In case 2 a side branch of the LAD was mistaken for the LAD. The change of the projection of CCTA separated the two vessels without difficulty and the occlusion was recanalised easily. In case 3 there was no stump and CAG could not differentiate between the side branch and main right coronary artery, which resulted in the failure. CCTA clearly showed the stump, and precision puncture recanalised the CTO. Case 4 was a CTO of the LAD, and the first attempt at recanalisation failed. The operator placed a stent in the first diagonal artery. Because of the stent, no stump was discernable. A precision puncture was performed

Figure 4 Coronary tomography angiography of patients at the second attempt. Patient No 2 (A) had a side branch (arrow) in the entry of chronic total occlusion. Patients No 3 (B), No 5 (C) and No 1 (D) had blunt stumps (arrow). The bending in the right coronary artery of patient No 7 (E) exceeded 45°. The angiogram of patient No 6 (F) was characterised by a long lesion.

with successful recanalisation. In case 5 the first attempt failed. CCTA showed a tortuous left circumflex artery (LCX). The use of a flexible soft wire resulted in successful recanalisation of the LCX. Despite CAG and CCTA guidance, PCI in cases 6 and 7 was not successful. In case 6 the procedure seemed to be easy, but the wire kept entering the dissection. In case 7 the first attempt failed. During a second attempt the wire was unable to reach the distal LAD and the procedure ended with implantation of the stent in the diagonal artery.

The patients were divided into groups for whom recanalization was a failure or a success. The J score was the independent predictor of failure, OR=0.290 (95% CI 0.158 to 0.533).

DISCUSSION

The main purpose of the study was to test if use of CCTA helped to increase the recanalisation rate. The clinical characteristics of the two groups of patients were similar, with no significant difference. Only two operators were involved in the study, so the confounding factors are minimal. In this study we used a dedicated image processing work station to analyse and

manipulate the images. The same investigator carried out the post-processing analysis and decided on the recanalisation strategy. The analysis involved calculation of the length and characteristics of the occlusion, the calibre of the artery, the best

Table 5 Second attempts

Patient No	Artery	Score	Anatomy	Solution	Results
1	CIR	3	No stump	Precision puncture	Success
2	LAD	3	Side branch	Reselect entry	Success
3	RCA	2	No stump	Reselect entry	Success
4	CIR	1	Bending	Soft wire	Success
5	LAD	3	No stump	Precision puncture	Success
6	LAD	4	Long	Unable to enter the true lumen	Failure
7	RCA	3	Bending	Dissection	Failure

CIR, circumflex artery; LAD, left anterior descending artery; RCA, right coronary artery.

projection for precision guidewire penetration, the use of side branch and calcification for landmarking and selection of most suitable guidewire. We expected a higher success rate under the guidance of CCTA.

The study did not show significant differences between CAG- and CCTA-guided PCI. The main outcome—the recanalisation rate—was almost same for the two groups. It was even slightly better in the CAG group, which we had not expected. The reason is not surprising. The Japanese operators have improved and disseminated the recanalisation technique worldwide,^{7–9} and further improvement would be difficult. The better visualisation of the occlusion achieved by CCTA does not improve the outcome. CTO PCI involves much personal experience and practice. In addition, it was impossible to completely blind my colleagues and contamination was unavoidable. Furthermore, as the study continues both sides are gaining experience and improving their technique, and they come to know each other. It is not possible to operate completely independently.

However, we found that CCTA-guided PCI does have advantages.⁶ In this study we developed our own technique to facilitate the recanalisation. This included estimation of the length and characteristics of the occlusion (soft, fibrotic or calcified lesions), the best projection for visualising the entry point for the precision puncture and a sequential guidewire technique (precision puncture, stiff wire for direction and penetration, fast drill, change of soft wire after successful penetration, use of side branch and calcification for location). The combination of CAG and CCTA (fusion technology) might contribute to the increased recanalisation rate.

For favourable CTOs the success rate was high, but unfavourable CTOs have a high failure rate.¹⁰ To make judgement easier, we used the J-CTO score to predict the recanalisation.⁹ Failure may occur for a variety of reasons.^{11–13} A super-long lesion and dissection are the two major reasons for stopping the procedure. Slow advancement of the guidewire, dissection re-entry with the help of a puncture technique, contralateral injection, docked wire technique and retrograde techniques all contributed to the success.^{14–16} Complications are also a main reason for terminating the procedure.¹⁷ Successful placement of the wire does not necessarily mean that the procedure will be a success. Occasionally, the balloon will not pass. Perforation occurred in one case, resulting in cardiac tamponade.

The results of CAG- and CCTA-guided PCI are similar. However, guided by CCTA five of the seven failures were successful at the second attempt. Before the second attempt the CCTA and CAG images were carefully reviewed to determine the causes of failure. The sample size was too small to prove that CCTA is better than CAG, but this study illustrates the complementary role of CCTA in difficult cases. The lessons we have learnt are that using the rotating function of CCTA we should select a stiff wire for precision puncture, correctly identify the true main vessel and correctly identify the side branch. Despite all these efforts a long lesion remains the most difficult challenge. A retrograde approach may be the last choice.¹⁸

The major limitations are twofold. First, the sample size is small which might result in insignificant difference. Second, the study is a cohort study which might have resulted in selection bias.

CONCLUSION

The occlusion could be visualised by soft tissue CT imaging. The length and calibre of the artery, the three-dimensional

orientation of the artery may help to guide the PCI. No difference was found between CCTA and CAG, possibly owing to the small sample size. In case of unfavourable CTO CCTA can be used to help guide recanalisation for cases of unfavourable CTO, whereas favourable CTOs do not need CCTA guidance.

Contributors SZ: collected data and wrote the paper. LG, YC: designed the project, and operators. QJ: operator. JG, BH: collected data.

Competing interests None.

Patient consent Obtained.

Ethics approval Ethical committee of the PLA General Hospital.

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