Diagnostic Accuracy of Coronary CT Angiography in Patients after Coronary Bypass Surgery: Evaluation of Grafts and Native Coronary Arteries

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Objective: To evaluate the diagnostic accuracy in the assessment of both grafts and native coronary arteries in patients after coronary artery bypass grafts (CABG) by coronary CT angiography (CCTA) in comparison to invasive conventional coronary angiography (CCA).
Material and Method: CCTA was performed in 54 symptomatic post-CABG patients. Two independent, blinded observers assessed all grafts and native coronary arteries for significant stenosis. CCA served as a reference standard. One hundred seventy two graft segments, 156 distal coronary run-offs, 314 grafted coronary segments, and 18 non-grafted coronary segments were analyzed.
Results: The diagnostic accuracy of CCTA for exclusion or detection of significant stenosis in venous grafts and non-grafted segments of native coronary arteries was 100%. Sensitivity, specificity, and positive and negative predictive values were all 100%. Sensitivity, specificity, and positive and negative predictive values to detect significant stenosis were 100%, 98%, 91%, and 100%, respectively, in arterial grafts, 100%, 99%,75%, and 100%, respectively, in distal runoffs, and 100%, 87%, 99%, and 100%, respectively, in grafted segments of native coronary arteries.
Conclusion: Non-invasive coronary CT angiography provides high diagnostic accuracy for evaluation of both bypass grafts and native coronary arteries, although, CCTA is more effective in evaluation of bypass grafts as compared to heavily calcified native coronary arteries.

Keywords: *Coronary artery bypass surgery, Computed tomography (CT), Coronary angiography, Coronary artery disease*

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Recurrent symptoms after coronary artery bypass graft surgery (CABG) may be caused by progression of disease, either in the native coronary arteries or in the venous or, more rarely, arterial grafts[1]. Up to 10% of grafts occluded during or shortly after surgery, and 59% of venous grafts and 17% of arterial grafts occluded within 10 years[2]. Therefore, comprehensive assessment of symptomatic patients after surgical revascularization should include venous and arterial bypass grafts and native coronary arteries. Although invasive conventional coronary angiography (CCA) is the gold standard study for detection of bypass graft disease, it is invasive procedure, carried potential risk of harm, and the engagement and visualization of arterial and venous bypass grafts frequently prolong procedure time and associated with increased radiation exposure and higher contrast use. Non-invasive coronary computed tomography angiography (CCTA) might be useful for reducing the procedure time and contrast load if it was proven to be reliable for evaluating bypass grafts and distal runoffs. Only a few studies in post-CABG patients had included the assessment of the native coronary arteries, and had shown only modest accuracy using 4- and 16-slice CT for the detection of obstructive disease[3,4].

The present study used 64-slice computed tomography (CT) scanners reported specificity values of 86%[5] and 76%[6], whereas up to 9% of non-grafted segments and distal runoffs were non-evaluable because of presence of coronary motion, severe

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coronary calcifications, or metal clip artifacts. The newer generation CT scanners may improve CCTA reliability and may overcome some of the imaging challenges after bypass surgery. The dual-source 128-slice CT scanner is equipped with two tube-detector systems rotating simultaneously, resulting in an improved temporal resolution of 83 ms[7]. Therefore, it was hypothesized that dual source CCTA should allow more accurate detection or exclusion of significant graft stenoses. In addition to assessment of CABG, distal coronary run-offs and non-grafted coronary arteries were included in this study.

Material and Method

Patient population

This retrospective study included 54 consecutive symptomatic patients after surgical revascularization who underwent both CCTA and CCA, between January 2013 and August 2013.

Exclusion criteria for CCTA included the presence of multiple ectopic beats, atrial fibrillation, pregnancy, renal failure, and a history of allergic reaction to iodine-containing contrast agents. The present study was approved by the Ethics Committee of the Faculty of Medicine, Khon Kaen University, Khon Kaen, Thailand, and informed consent was obtained from all patients.

Coronary CT angiography (CCTA) scanning protocol

All patients were scanned using a 128-slice dual-source CT scanner (Somatom Definition, Siemens Healthcare, Forchheim, Germany). The system is equipped with two X-ray tubes and two corresponding detectors mounted on a single gantry with an angular offset of 90°[7]. The CCTA uses automatic tube current modulation in x, y, z directions (Care Dose 4D, Siemens Healthcare). The adaptive electrocardiography (ECG) pulsing (full tube current during 30% to 65% of the RR interval, reduced tube current: 20% of maximum) was applied in all patients. The CCTA scan parameters were as follows, two X-ray sources, detector collimation 32x0.6 mm with double sampling by rapid alteration of the focal spot in the longitudinal direction (Z-flying focal spot)[8], 330 ms rotation time, 120 Kv tube voltage. The pitch varied between 0.2 for low heart rates (<50 beats/min) and 0.55 for high heart rates (>100 beats/min), with individually adapted pitch values for heart rates >50 and <100 beats/min. Image acquisitions were performed during inspiratory breath-holds. To familiarize the patient with the protocol, breath-holding was practiced before the examination. An iodinated contrast agent bolus of 80 to 100 ml was injected with a mean flow rate of 5 ml/sec followed by a 50 ml saline flush. For timing purposes, an automated bolus-tracking software was used to synchronize the data acquisition with the arrival of contrast in the bypass grafts and native coronary arteries. Studies were acquired in the cranio-caudal direction and the scan range was extended to the subclavian artery level in patients with internal mammary artery grafts.

CCTA image analysis

CCTA image analysis was performed by two experienced cardiovascular and thoracic radiologists in consensus (with 9 and 7 years of experience in examining cardiovascular and thoracic CT scan), and blinded to the invasive conventional coronary angiographic (CCA) results.

Arterial and venous grafts

In the case of a jump graft (≥2 coronary anastomoses per arterial or venous graft), the graft was divided into graft segments. All graft segments between the proximal anastomoses and each coronary insertion were evaluated and classified as occluded, significant stenosis (≥50% diameter reduction), or no significant stenosis (<50% diameter reduction) (Fig. 1).

Distal coronary run-offs and native coronary arteries

Native coronary anatomy was assessed in a standardized manner by dividing the coronary arterial tree into 17 segments according to a modified American Heart Association classification[9]. The distal runoff segments included the segment at which the graft was inserted and all segments located distally to the inserted segment. Native coronary segments were divided into grafted and non-grafted segments. The grafted segments included all segments located proximal to where the graft was inserted. First, axial slices were visually examined for the presence of significant narrowing by determining the presence of ≥50% reduction of luminal diameter as recommended by the society of cardiovascular computed tomography (SCCT) guidelines for the interpretation and reporting of CTA[10]. CCTA analysis was assisted by curved multiplanar reconstructions of all vessels. Stenosis severity was estimated by comparing the luminal diameter at the narrowing with (relatively) non-diseased locations immediately proximal and/or distal to the lesion. Subsequently, three-dimensional volume-rendered reconstructions were used to visualize the course of the grafts in relation to the coronary arteries.

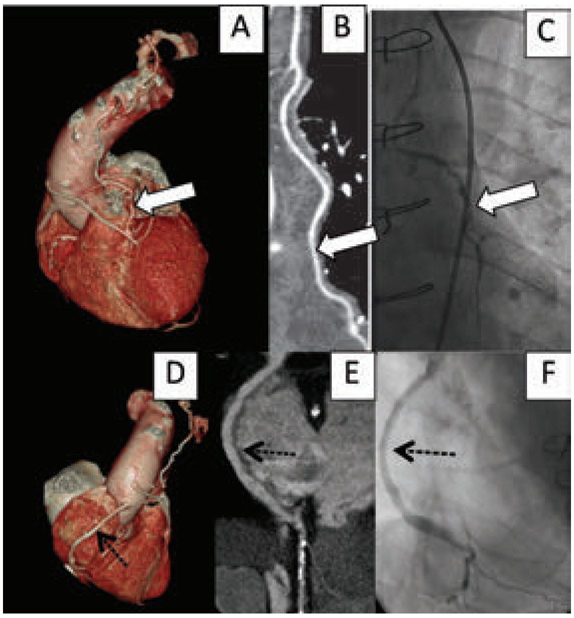

Fig. 1 A 62 year-old-man with recurrent chest pain after coronary artery bypass graft surgery 5 years earlier. CCTA volume rendering technique image (A, D) and curved multiplanar reformation image (B, E) showed patent LIMA to distal LAD (arrows) and patent SVG to distal RCA (dashed arrows). Corresponding conventional coronary angiogram (C, F) confirms CT findings (arrow and dashed arrow) (LIMA = left internal mammary artery; LAD = left anterior descending artery; SVG = saphenous vein graft; RCA = right coronary artery).

Conventional coronary angiography (CCA)

CCA was performed according to standard techniques. Images were evaluated by an experienced cardiologist blinded to CCTA results, who identified all graft segments, native coronary arteries segments, and distal runoffs. Each segment was evaluated for the presence of significant stenosis by determining the presence of ≥50% luminal diameter reduction in the two orthogonal angiographic views with most severe luminal narrowing. Classification criteria for segments and lesions were identical to those used for CCTA.

Statistical analysis

The diagnostic accuracy of CCTA for the detection of significant stenosis as defined by CCA was presents as sensitivity, specificity, and positive and negative predictive values, including 95% confidence intervals (CI) as the precision of the diagnostic parameters. Continuous and categorical data were expressed as mean ± SD and number (%) respectively. Statistical analyses were performed using SPSS software version 16 (SPSS, Inc., Chicago, IL, USA). A significance level of $p<0.05$ was considered as statistically significant and all reported p-values were two-sided.

Results

Patient clinical characteristics are presented in Table 1. Fifty-four patients (43 men, 11 women; mean age 68±11 years; range, 38-91 years) were included in the present study. The median time interval between CCTA and CCA was four days (range, 0-14 days) and there were no clinical events between the two studies in any patient. The mean interval between bypass surgery and CCTA was 10.2±5.8 years (range 1-16 years). Fifty-three patients had venous bypass grafts and 52 had arterial bypass grafts. Of the 112 venous grafts, 104 were anastomosed to a single coronary branch and eight were jump grafts with two

Table 1. Patient characteristics

Characteristic	Number of patients (%) (n = 54)
Age (years), mean ± SD (range)	68.0±11 (38-91)
Male	43 (80)
Height (cm), mean ± SD	162.9±14
Weight (kg), mean ± SD	60.9±18
Body mass index (kg/m²), mean ± SD (range)	25.6±8 (23-35)
History	
Family history of coronary disease	21 (39)
Current smoker	10 (19)
Previous myocardial infarction	31 (57)
Stroke/transient ischemic attack	5 (9)
Diabetes mellitus	22 (41)
Hypertension*	39 (72)
Hypercholesterolemia[µ]	45 (83)
Graft anatomy per patient	
Single graft	1 (2)
Two grafts	2 (4)
Three grafts	49 (90)
More than three grafts	2 (4)
Venous and arterial grafts	51 (94)
Venous grafts, no arterial grafts	2 (4)
Arterial grafts, no venous grafts	1 (2)

* Blood pressure >140/90 mmHg or treatment for hypertension

[µ] Total cholesterol >180 mg/dl or treatment for hyper-cholesterolemia

Table 2. Diagnostic accuracy of coronary computed tomography angiography (CCTA) for the detection of significant graft and native coronary artery stenosis

	N	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)	TP	TN	FP	FN
All grafts	164	100 (93-100)	99 (91-100)	99 (93-100)	100 (95-100)	72	91	1	0
Arterial grafts	52	100 (91-100)	98 (90-100)	91 (85-96)	100 (94-100)	10	41	1	0
Venous grafts	112	100 (95-100)	100 (98-100)	100 (95-100)	100 (98-100)	62	50	0	0
All graft segments	172	100 (92-100)	99 (91-100)	99 (94-100)	100 (95-100)	78	93	1	0
Arterial grafts	52	100 (91-100)	98 (90-100)	91 (85-96)	100 (94-100)	10	41	1	0
Venous grafts	120	100 (94-100)	100 (98-100)	100 (96-100)	100 (98-100)	68	52	0	0
Native coronary arteries									
Distal runoffs	93	100 (96-100)	99 (86-100)	75 (67-93)	100 (97-100)	3	83	1	0
All grafted segments	314	100 (91-100)	87 (73-95)	99 (92-100)	100 (96-100)	288	26	12	2
All nongrafted segments	18	100 (96-100)	100 (93-100)	100 (89-100)	100 (98-100)	1	17	0	0

95% CI = 95% confidence interval; NPV = negative predictive value; PPV = positive predictive value; N = number of segments; TP = true positive; TN = true negative; FP = false positive; FN = false negative

consecutive coronary anastomoses. All 52 arterial grafts were anastomosed to a single coronary branch.

Two patients previously underwent percutaneous coronary intervention (PCI) with stent implantation, with four coronary stents.

The diagnostic accuracy of coronary computed tomography angiography (CCTA) for the detection of significant graft and native coronary artery stenosis is detailed in Table 2.

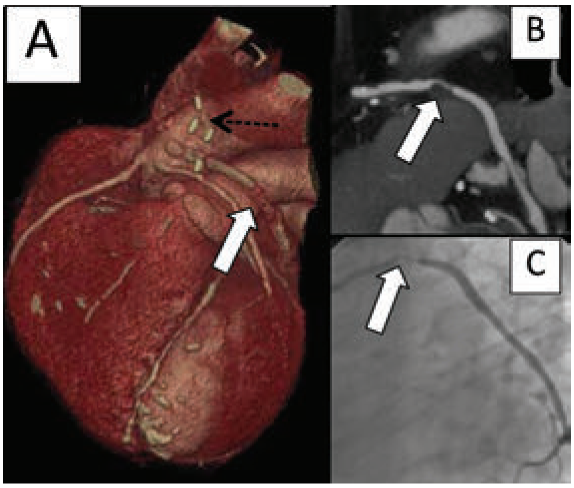

Fig. 2 A 58 year-old-man with progressive chest pain after coronary artery bypass graft surgery 11 years later. CCTA volume rendering technique image (A), curved multiplanar reformation image (B) and conventional coronary angiogram (C) showed occluded LIMA graft (dashed arrow) and significant stenosis of body of SVG to OM branch of LCX (arrows) (LIMA = left internal mammary artery; SVG = saphenous vein graft; OM = obtuse marginal branch; LCX = left circumflex coronary artery).

Bypass grafts

Fifty-two arterial grafts and 112 venous grafts (120 venous graft segments) and 172 graft segments were analyzed. CCTA correctly assessed all venous arterial grafts and detected one significant stenotic and 67 occluded segments (Fig. 1, 2; true positive). CCTA detected nine occluded and one stenotics arterial graft segments (Fig. 1, 3; true positive). Only one arterial graft was incorrectly diagnosed with significant stenosis on CCTA due to metallic artifacts and small size of this arterial graft (Fig. 4; false positive) Thus, the diagnostic accuracy of CCTA for exclusion or detection of significant stenosis in venous grafts

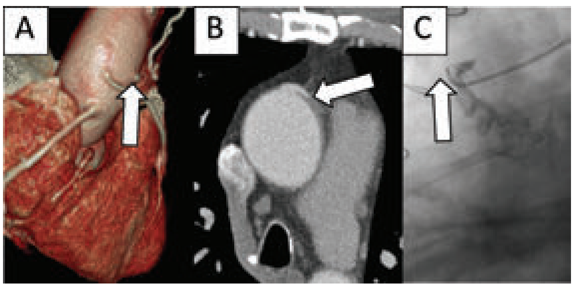

Fig. 3 A 62 year-old-man with recurrent chest pain after coronary artery bypass graft surgery 5 years previously. CCTA volume rendering technique image (A) and axial image (B) showed occluded SVG (arrows). Corresponding conventional coronary angiogram (C) confirms CT findings (arrow) (SVG = saphenous vein graft).

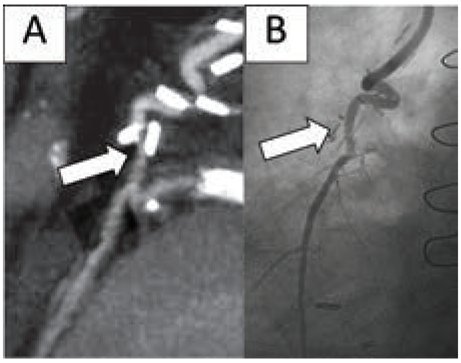

Fig. 4 A75-year-old man who had an off-pump LIMA to LAD bypass graft surgery 5 year ago presenting with chest pain. CCTA curved multiplanar reformation image (A) misinterpreted as significant stenosis at distal part of LIMA graft (arrow) due to metallic artifacts. There was no significant stenosis of the LIMA graft on conventional coronary angiogram (B) and represents a false-positive finding (LIMA = left internal mammary artery; LAD = left anterior descending artery).

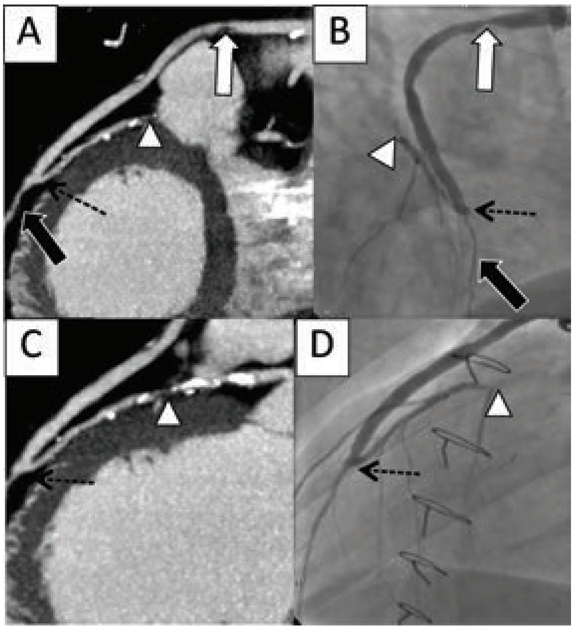

Fig. 5 A 58 year-old-woman with stable angina pectoris after coronary artery bypass graft surgery 7 years earlier. Curved multiplanar reformation image (A, C) and conventional coronary angiogram (B, D) that showed significant stenosis of the proximal part of the SVG to distal LAD (arrows) with a patent distal anastomotic site (dash arrows). Total occlusion of mid LAD (arrow head) and patency of distal runoff (black arrows) are detected (SVG = saphenous vein graft; LAD = left anterior descending artery).

were 100% (sensitivity, specificity, and positive and negative predictive values were all 100%). Sensitivity (95% confidence interval (CI)), specificity (95% CI), positive (95% CI), and negative predictive value (95% CI) to detect significant stenosis were 100% (91-100), 98% (90-100), 91% (85-96), and 100% (94-100), respectively, in arterial grafts (Table 2).

Distal runoffs

According to the CCA, patent graft segments supplied 93 distal coronary runoffs. CCTA detected all lesions (3/3), although there was an overestimation of stenosis that occurred in one segment due to heavily calcified plaque.

Grafted segments of native coronary arteries

One hundred fifty eight coronary arteries (right coronary artery 92%, left main 100%, left anterior descending artery 100%, and left circumflex artery 96%) that included 314 segments were revascularized by bypass grafting. CCTA detected 300 significant stenoses, including 168 (56%) total occlusions, and 12 lesions were overestimated. Sensitivity, specificity, and positive and negative predictive value to detect significant stenosis were 100%, 87%, 99%, and 100%, respectively, in grafted segments of native coronary arteries.

Non-grafted segments of native coronary arteries

Four coronary arteries included 18 segments that were not revascularized by bypass graft surgery. CCTA correctly identified one non-grafted segment with significant stenosis. In addition, in 17 non-grafted segments, CCTA correctly ruled out the presence of significant stenosis. Thus, the diagnostic accuracy of CCTA for exclusion or detection of significant stenosis in non-grafted segments of native coronary arteries was 100% (sensitivity, specificity, and positive and negative predictive values were all 100%).

Discussion

Non-invasive coronary CTA (CCTA) demonstrated a very high diagnostic performance for the detection of obstructive graft disease, with a sensitivity of 100% for occluded grafts and sensitivities ranging from 80% to 100% for the detection of significant stenosis[5,6,11-15]. Few data are available reporting on the diagnostic performance of CCTA for the detection of significant stenosis in the native coronary arteries. Two studies[3,5] reported specificity for the detection of significant stenoses of

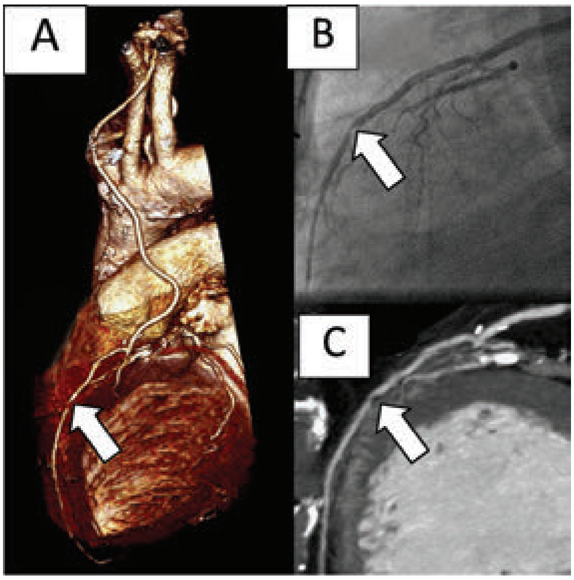

Fig. 6 A 67 year-old-man with recurrent chest pain after coronary artery bypass graft surgery 14 years before. CCTA volume rendering technique image (A), curved multiplanar reformation image (C) and conventional coronary angiogram (B) showed a patent LIMA graft to LAD with significant stenosis of the distal runoff (arrows). (LIMA = left internal mammary artery; LAD = left anterior descending artery).

76% and 86% in non-grafted coronary arteries and 90% and 93% in distal runoffs. Importantly, overestimation of stenosis frequently occurred and 9% to 25% of native segments were unavailable. The latest dual source CT technology allows acquisition of images during a shorter time window of the heart cycle, resulting in images with less residual coronary motion and more precise delineation of stenoses[8], in particular, at the graft distal anastomotic site and smaller distal runoffs. In addition, fast scanning of the whole thorax can be performed in short manageable breath holds (10 to 15 sec), which is important in the assessment of arterial grafts. The relative immobility, larger diameter size and less calcification make bypass grafts relatively approachable by non-invasive imaging techniques, such as coronary CT angiography (CCTA).

Hence, the attempt to evaluate whether non-invasive dual-source CCTA would provide reliable evaluation of both bypass grafts and native coronaries was accomplished. A segment-by-segment analysis, rather than a per patient analysis, to provide anatomic information about bypass grafts, distal runoffs, and native coronary segments was performed.

The present study demonstrated excellent diagnostic accuracy for the complete assessment of bypass grafts and native coronary arteries using the 128-slice dual-source CT scanner. Furthermore, the present study demonstrated that CCTA had the capability of assessment of grafts, without exclusions because of image quality and demonstrated a very high diagnostic accuracy for the detection of obstructive graft disease, with sensitivities of 100% for detection of significant stenosis of both venous and arterial grafts, and specificity of 100% and 98% for detection of significant stenosis of venous and arterial grafts, respectively. Metallic artifacts of vascular clips and sternal wires occurred, but because of the relatively large diameter and fewer motion artifacts of bypass grafts these high-density artifacts did not affect assessment accuracy.

For comprehensive evaluation of post-coronary arterial bypass graft surgery (CABG) patients, native coronary arteries need to be assessed. Assessment of non-grafted coronary artery segments yielded a 100% of sensitivity and specificity. Importantly, the majority of smaller distal runoffs and distal anastomosis sites showed good image quality and could be interpretable. Furthermore, CCTA yielded 100% negative predictive value of distal runoffs, grafted, and non-grafted segments of native coronaries.

Conventional coronary angiography (CCA) is still the gold standard in the evaluation of both coronary artery and graft statuses, but its use is restricted by the invasive nature of the procedure and has some practical disadvantages, such as the requirement for selective contrast injection especially when the surgical history is incomplete. CCTA allows comprehensive graft visualization, including the anastomosis site and identity of distal runoffs. Therefore, CCTA is increasingly used prior to planned invasive coronary angiography, to assure optimal angiography of both coronary arteries and grafts.

Despite these promising initial results, the present study has potential limitations. First, because the method of enrollment included some patients who underwent CCA because of CCTA results, selection bias was introduced whereby the calculated sensitivity of CCTA may have been overestimated. Selection bias, however, tends to underestimate specificity, which was still high in the present study, and may have only had a minimal effect on positive and negative predictive values (PPV and NPV) because patient enrollment after initial CCTA was independent of the actual true disease status from the CCA. Secondly, as CCTA and CCA analysis were performed blinded, differences in segment allocation may have occurred. Thirdly, because the population consisted of symptomatic patients after bypass surgery with a high incidence of graft and/or coronary artery disease, the results may not be applicable to a lower risk (non-symptomatic) population. Graft occlusion may occur without ischemic consequences in case of competitive flow or in the presence of non-viable myocardial scar. Particularly in the patients with chronic arterial disease, it may not be possible to determine the need for revascularization based on CCTA assessment alone. Lastly, the results represent a single-center experience and generalizability of the present results may therefore be limited.

Conclusion

The present study demonstrated that noninvasive CCTA has a high diagnostic accuracy for evaluation both bypass grafts and native coronary arteries, although, CCTA is more effective in evaluation of bypass grafts as compared with heavily calcified native coronary arteries. CCTA should not be considered as a substitute for, but rather as complementary to conventional coronary angiography (CCA) in the diagnostic work up of symptomatic post CABG patients and may facilitate planning of subsequent revascularizations by providing accurate anatomical site of graft origin, saving considerable contrast load, procedure time, and radiation exposure. CCA may still be required to confirm of obstructive disease in distal runoffs and native coronary arteries.

What is already known on this topic?

Non-invasive coronary CTA (CCTA) demonstrated a very high diagnostic performance for the detection of obstructive graft disease and native coronary arteries using 64-slice CT.

What this study adds?

The present study, using the latest 128-slice dual source CT technology allows acquisition of images during a shorter time window of the heart cycle, resulting in images with less residual coronary motion and more precise delineation of stenoses, in particular, at the graft distal anastomotic site and smaller distal runoffs. In our knowledge, there is no report of diagnostic accuracy of CCTA in patient after coronary bypass surgery using dual source CT for evaluation both grafts and native coronary arteries. For comprehensive evaluation of post-coronary arterial bypass graft surgery (CABG) patients, native coronary arteries need to be assessed. Importantly, the majority of smaller distal runoffs and distal anastomosis sites showed good image quality and could be interpretable with excellent diagnostic accuracy for the complete assessment of both bypass grafts and native coronary arteries in the present study.

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Potential conflicts of interest

None.

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ความแม่นยำในการวินิจฉัยสิ่งปลูกถ่ายและหลอดเลือดหัวใจตีบตันในผู้ป่วยที่ได้รับการผ่าตัดทำทางเบี่ยงหลอดเลือดหัวใจโดยเครื่องเอกซเรย์คอมพิวเตอร์

นฤมล เชาว์สุวรรณกิจ, ภัทรพงษ์ มกรเวส, ทรงศักดิ์ เกียรติชูสกุล, ไชยสิทธิ์ วงศ์วิภาพร, ชูศักดิ์ คุปตานนท์

วัตถุประสงค์: *เพื่อศึกษาความแม่นยำของการวินิจฉัยสิ่งปลูกถ่ายและหลอดเลือดหัวใจตีบตันในผู้ป่วยที่ได้รับการผ่าตัดทำทางเบี่ยงหลอดเลือดหัวใจโดยเครื่องเอกซเรย์คอมพิวเตอร์เปรียบเทียบกับการฉีดสารทึบรังสีถ่ายภาพหลอดเลือดหัวใจโดยการสวนหัวใจ*
วัสดุและวิธีการ: *เป็นการศึกษาแบบตัดขวาง มีผู้ป่วย 54 ราย ที่ได้รับการตรวจสิ่งปลูกถ่ายและหลอดเลือดหัวใจด้วยเครื่องเอกซเรย์คอมพิวเตอร์และการสวนหัวใจ การประเมินผลโดยเอกซเรย์คอมพิวเตอร์ทำโดยผู้ประเมินที่ไม่ทราบผลการสวนหัวใจ*
ผลการศึกษา: *สิ่งปลูกถ่ายที่นำมาศึกษารวมเป็น 172 segments, 156 distal coronary run-offs, หลอดเลือดหัวใจที่ได้รับการทำทางเบี่ยง 314 segments และหลอดเลือดหัวใจที่ไม่ได้รับการทำทางเบี่ยง 18 segments พบว่าเครื่องเอกซเรย์คอมพิวเตอร์สามารถแสดงรอยโรคได้ผลแม่นยำมากโดยสามารถวินิจฉัยรอยโรคของสิ่งปลูกถ่ายที่ทำจากหลอดเลือดดำและหลอดเลือดหัวใจที่ไม่ได้รับการทำทางเบี่ยงได้ถูกต้องร้อยละ 100 (ความไว, ความจำเพาะ positive และ negative predictive value จากการประเมินมีค่าร้อยละ 100 ทั้งหมด) เครื่องเอกซเรย์คอมพิวเตอร์สามารถแสดงรอยโรคได้โดยมี ความไว ความจำเพาะ positive และ negative predictive value จากการประเมินสิ่งปลูกถ่ายที่ทำจากหลอดเลือดแดงมีค่าร้อยละ 100, 98, 91, และ 100 ตามลำดับ เมื่อประเมิน distal coronary run-offs มีค่าร้อยละ 100, 99, 75, และ100 ตามลำดับ และเมื่อประเมินหลอดเลือดหัวใจที่ได้รับการทำทางเบี่ยง มีค่าร้อยละ 100, 87, 99, และ 100 ตามลำดับ ประเมินหลอด*
สรุป: *การวินิจฉัยสิ่งปลูกถ่ายและหลอดเลือดหัวใจตีบตันในผู้ป่วยที่ได้รับการผ่าตัดทำทางเบี่ยงหลอดเลือดหัวใจโดยเครื่องเอกซเรย์คอมพิวเตอร์มีความแม่นยำมากและมีประสิทธิภาพในการตรวจสิ่งปลูกถ่ายดีกว่าการตรวจหลอดเลือดหัวใจ*