Circulation
JOURNAL OF THE AMERICAN HEART ASSOCIATION

American Heart Association®
Learn and Live℠

Intravenous Coronary Angiography by Electron Beam Computed Tomography : A Clinical Evaluation

Benno J. Rensing, Alfons Bongaerts, Robert-Jan van Geuns, Peter van Ooijen, Matthijs Oudkerk and Pim J. de Feyter

Circulation 1998;98;2509-2512
Circulation is published by the American Heart Association. 7272 Greenville Avenue, Dallas, TX 72514
 Print ISSN: 0009-7322. Online ISSN: 1524-4539

Intravenous Coronary Angiography by Electron Beam Computed Tomography

A Clinical Evaluation

Benno J. Rensing, MD; Alfons Bongaerts, MD; Robert-Jan van Geuns, MD; Peter van Ooijen, MSc; Matthijs Oudkerk, MD; Pim J. de Feyter, MD

***Background*—**Noninvasive detection of coronary stenoses with electron beam CT (EBCT) after intravenous injection of contrast medium has recently emerged. We sought to determine the diagnostic accuracy of EBCT angiography in the clinical setting using conventional coronary angiography as the "gold standard."

***Methods and Results*—**Thirty-seven patients (30 men) were investigated. After intravenous injection of 150 mL of contrast medium, 40 to 60 consecutive transaxial tomograms, covering the proximal and middle parts of the coronary arteries, were obtained with ECG triggering at end diastole during breath-holding. Three-dimensional reconstructions of the proximal and middle parts of the arteries were compared with the conventional angiograms. Of the 259 proximal and middle coronary segments, 211 (81%) were analyzable by EBCT. Of the left anterior descending coronary artery (LAD) segments, 95% were assessable. Right coronary artery (RCA) and left circumflex artery (LCx) segments were assessable in 66% and 76%, respectively. Overall sensitivity and specificity to detect a >50% diameter stenosis were 77% and 94%, respectively. This was 82% and 92% for the LAD, 60% and 97% for the RCA, and 83% and 89% for the LCx (all figures based on assessable lesions).

***Conclusions*—**Intravenous EBCT coronary angiography is a promising coronary imaging technique. The technique is not yet robust enough to be an alternative to conventional coronary angiography. It can detect and rule out significant coronary artery disease of the left main proximal and mid portions of the LAD with good accuracy. **(*Circulation*. 1998;98:2509-2512.)**

Key Words: angiography ■ tomography

Recently, electron beam CT (EBCT) has emerged as an imaging technique that allows visualization of epicardial coronary arteries after intravenous injection of contrast material.[1–5] Few data concerning the diagnostic accuracy of EBCT coronary angiography are available at the moment. The latest upgrading of the scanner allows improved resolution in the scanning direction. Slice thickness (collimation) and table feed after each scan can be decreased to 1.5 mm. The purpose of the present study was to compare noninvasive EBCT coronary angiography with conventional coronary angiography in the clinical setting and to determine the diagnostic accuracy of EBCT angiography.

Methods

Thirty-seven patients who underwent diagnostic coronary angiography were asked to participate in the study and gave informed consent. The study was approved by the Institutional Review Board. Two patient slots per week for cardiac research were available at the EBCT site. Therefore, our patient population is not strictly consecutive. All patients who met the inclusion criteria were approached until the 2 slots for that week were filled. Exclusion criteria were previous bypass operation or stent implantation, severe lung disease or comorbidity that made breath-holding difficult, renal failure, nonsinus rhythm, and unstable clinical condition.

EBCT Angiography

The EBCT scanner (Siemens Evolution) allows the acquisition of high-resolution tomograms in 100 ms, which is fast enough to prevent cardiac motion artifacts. A description of scanner specifications can be found elsewhere.[6] Contrast transit time was determined by injection of 10 mL of contrast medium (Iopromide, Schering) at a rate of 4 mL/s through an antecubital vein and visualization of the passage of the contrast through the ascending aorta by 20 consecutive tomograms. The time from contrast injection to peak density of the aorta was considered the transit time. Image acquisition started with the injection of 150 mL contrast medium at 4 mL/s. At transit time, tomography commenced just proximal to the takeoff of the left main (LM) coronary artery after an ECG trigger at 80% of the RR interval. The table increment after each tomogram was 1.5 mm. A total of 40 to 60 tomograms were acquired. Because of patient limitations (maximal breath-hold time) and scanner limitations (1 scan per heart cycle and 1.5-mm tomogram thickness), only the proximal and middle parts of the coronary arteries could be visualized consistently. To decrease breath-holding time, atropine 0.5 to

Received August 18, 1998; revision received October 5, 1998; accepted October 8, 1998.

From the Thoraxcenter (B.J.R., R.J.G., P.O., P.J.F.) and Daniel den Hoed Kliniek (A.B., M.O.), Rotterdam, Netherlands

Correspondence to Benno J. Rensing, MD, Catheterization Laboratory, Thoraxcenter BD416, Dr Molewaterplein 40, 3015 GD Rotterdam, Netherlands. E-mail rensing@card.azr.nl

***Circulation* is available at http://www.circulationaha.org**

1.0 mL was administered if heart rate was <60 bpm. Radiation dose was estimated to be <20 mGy.

Three-Dimensional Reconstruction

The 2-dimensional tomograms were transferred to a Silicon Graphics workstation, where they were stacked and interpolated to form a 3-dimensional (3D) volume by use of Voxel-View volume-rendering software. Postprocessing techniques were applied to better visualize the coronary arteries between the other contrast-enhanced cardiac structures.[7,8] Average postprocessing time was 15 to 20 minutes (Figure 1). To selectively visualize the coronary lumen, renderings were made with a lower threshold of 110 Hounsfield units. Two cardiologists unaware of the results of the selective coronary angiogram or the EBCT angiograms independently evaluated either EBCT angiograms (the 3D reconstructions and the individual tomograms) or the selective coronary angiograms. The coronary tree was divided into proximal, middle, and distal segments according to AHA guidelines.[9] The proximal and middle segments were graded as assessable or nonassessable. Then they were graded as having either no significant disease (<50% diameter stenosis) or significant disease (≥50% diameter stenosis). In case of disagreement, a third cardiologist decided.

Statistics

The selective angiogram served as the "gold standard" for determination of the diagnostic value of the noninvasive EBCT coronary angiogram. The diagnostic accuracy of EBCT angiography is expressed as sensitivity, specificity, and positive and negative predictive value.

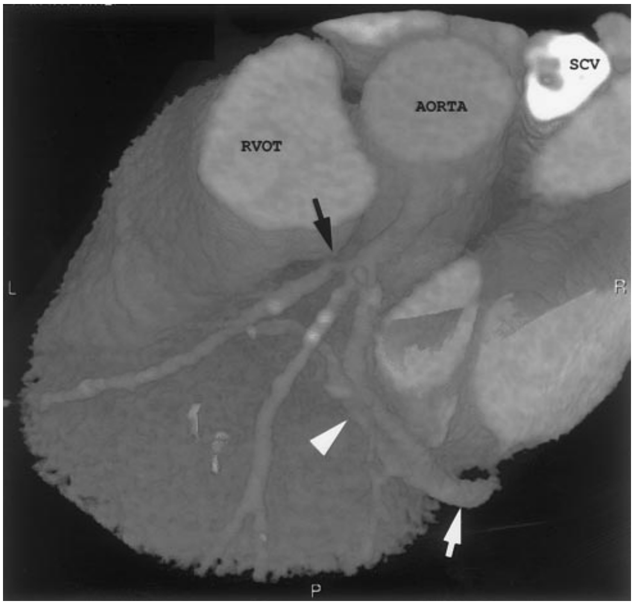

Figure 1. 3D rendering of left coronary artery. At trifurcation of LAD, intermediate branch, and LCx, stenosis in LAD can be seen (black arrow). Arrowhead indicates great cardiac vein on entering coronary sinus. Later, it blends with LCx (white arrow). RVOT indicates right ventricular outflow tract; SCV, superior caval vein.

Results

Thirty-seven patients (30 men) underwent both conventional and EBCT coronary angiography. Mean age was 58±6 years (range, 42 to 82 years). Mean weight was 70±10 kg, and mean height was 171±12 cm. Mean time interval between both examinations was 10±13 days. At conventional angiography, 9 patients had no significant coronary stenosis, 12 had 1-vessel disease, 11 had 2-vessel disease, and 5 had 3-vessel disease. LM disease was present in 1 patient. Mean heart rate during the EBCT angiography was 72±10 bpm (60 to 105 bpm). Mean breath-holding time was 36 seconds. After mild hyperventilation and instruction, all patients were able to hold their breath for ≥40 tomograms. Atropine 0.5 to 1 mg was administered in 25 patients. Conventional angiography showed 1 significant LM lesion, 15 right coronary artery (RCA) lesions, 16 left anterior descending coronary artery (LAD) lesions, and 8 left circumflex (LCx) lesions in the proximal and middle portions of the coronary tree. Of the 259 proximal and middle coronary artery segments, 211 (81%) were assessable by EBCT angiography (Table 1). Five (33%) of the proximal and middle RCA lesions and 2 (25%) of the proximal and middle LCx lesions were located in segments deemed not assessable by EBCT angiography. Table 2 summarizes diagnostic accuracy parameters of EBCT angiography. The causes for the inability to assess 46 proximal and middle coronary segments with EBCT are summarized in Table 3. The causes for false-negatives or false-positives are given in Table 4. The major cause of false-positive classification was poor opacification in small distal coronary arteries. Calcification of the vessel wall obscuring a luminal narrowing was the major cause of false-negative classification. The only reported side effect of atropine was oral dryness in 5 patients. Angina occurred once, with reversal after oral nitroglycerin.

Discussion

Others[1–5] and we have shown that EBCT coronary angiography is feasible and safe. It allows visualization of the proximal and middle coronary arteries in a majority of patients. With special computer software, the individual tomograms can be stacked and 3D renderings of the coronary arteries constructed.[7,8]

Limitations of the Technique

The inability to assess coronary anatomy in a large proportion of mid RCA and LCx lesions requires further improvement of the technique. Conversely, all but 1 of the LM arteries and 95% of the proximal and mid LAD segments were assessable by current EBCT with a good diagnostic accuracy (Table 2). Breath-holding limitations and single tomogram acquisition per heart cycle restrict the volume of the heart that can be scanned during 1 contrast injection. Therefore, distal coro-

TABLE 1. No. of Segments Assessable

Segment	n (%)
RCA proximal	33/37 (89)
RCA middle	16/37 (43)
LM	36/37 (97)
LAD proximal	35/37 (95)
LAD middle	35/37 (95)
LCX proximal	33/37 (89)
LCX middle	23/37 (62)
Total	211/259

TABLE 2. Diagnostic Accuracy for Detection of a >50% Diameter Stenosis of EBCT Angiography*

	Total	LM	LAD	LCx	RCA
Sensitivity, %	77	100	82	83	60
Specificity, %	94	100	92	89	97
PPV, %	73	100	78	50	86
NPV, %	95	100	94	97	90

*Calculated for 211 assessable segments on a total of 259 proximal and middle coronary segments.

PPV indicates positive predictive value; NPV, negative predictive value.

nary arteries are only rarely visualized. Although one could argue whether stenoses in small distal coronary arteries have important symptomatic or prognostic meaning per se, visualization of the posterior descending artery is important and should be possible. A second contrast injection can visualize the distal part of the coronary trajectory, but at the expense of doubling the contrast volume (Figure 2). To accurately visualize coronary arteries <2 mm (the major cause of false-positive results and nonassessability), spatial resolution needs improvement.

Technical Improvements

A recently introduced new detector array is expected to improve in-plane resolution by 30%. This will probably increase assessability and diagnostic accuracy in small coronary vessels and might improve discrimination of overlapping contrast-filled structures. At the moment, the scanner can make only 1 tomogram per heart cycle. Ideally, the complete heart should be scanned within a few heartbeats, thereby shortening breath-holding time, decreasing the deleterious effect of arrhythmias on imaging, and reducing the total amount of contrast medium necessary for opacification. For this, the scanner has to be modified to allow acquisition of multiple simultaneous parallel tomograms and thus become more of a volume scanner. Finally, to prevent end-diastolic motion artifacts of the RCA, tomogram acquisition time <100 ms and true end-diastolic ECG (R wave) triggering are necessary. A solution to the problem of circular calcification of the vessel wall (a major source of false-negatives) might be to visualize the coronary artery from the inside. A postprocessing technique called "fly-through" tracks the contrast-enhanced lumen of the artery on the individual tomograms. After stacking and interpolation, the computer constructs a movie that gives the illusion of traveling through the artery.

TABLE 3. Causes for Nonassessability of 48 Proximal and Middle Coronary Segments

	LAD, n (%)	LM, n (%)	RCA, n (%)	LCx, n (%)
Scanning started below ostium	1 (25)	1 (100)	...	...
Circular calcification	2 (50)*	...	...	...
Cardiac motion artifacts	...	...	7 (28)	...
Breathing artifact	1 (25)	...	...	...
Blending with contrast-filled structures	...	...	5 (20)	4 (22)
Distal to total occlusion	...	...	3 (12)	1 (6)
Small vessel (<2 mm)	...	...	3 (12)	10 (56)
Poor distal opacification	...	...	3 (12)	3 (17)
Arrhythmia	...	...	3 (12)	...
Distal part not covered by tomograms	...	...	1 (4)	...

*1 patient.

TABLE 4. Reasons for Misclassification of Coronary Segments

	LAD, n	RCA, n	LCx, n
False positives			
Scanning started too low	2*	...	...
Premature atrial complex	1	...	...
Small distal artery (<2 mm)	1	...	5
Breathing artifact	...	1	...
False negatives			
Heavy calcification obscuring lumen	3†	2	...
Overlap with right auricle	...	1	...
Overlap with coronary sinus	...	...	1
Diastolic motion artifact	...	1	...

*1 patient; †2 patients.

Conclusions

EBCT coronary angiography is a technique under development and is currently not an alternative to conventional coronary angiography. At the present time, it can detect and rule out significant coronary artery disease of the proximal and middle portions of the LAD with good accuracy and thus may provide us with important prognostic information.

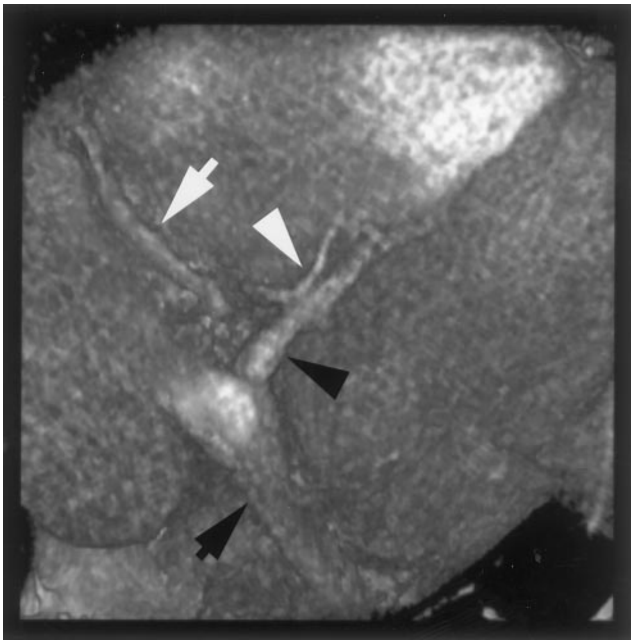

Figure 2. 3D rendering of inferior side of heart after second contrast injection. Black arrowhead indicates middle cardiac vein entering coronary sinus (black arrow); white arrow, distal RCA; and white arrowhead, small posterior descending artery running parallel to vein. Discontinuity of RCA at crux cordis is caused by partial intramural course. On individual tomograms, absence of a stenosis could be observed.

References

1. Moshage WE, Achenbach S, Seese B, Bachmann K, Kirchgeorg M. Coronary artery stenoses: three dimensional imaging with electrocardiographically triggered, contrast enhanced, electron beam CT. *Radiology*. 1995;196:707–714.
2. Schmermund A, Rensing BJ, Sheedy PF, Bell MR, Rumberger JA. Intravenous electron-beam computed tomographic coronary angiography for segmental analysis of coronary artery stenoses. *J Am Coll Cardiol*. 1998;31:1547–1554.
3. Achenbach S, Moshage W, Bachmann K. Detection of high-grade restenosis after PTCA using contrast-enhanced electron beam CT. *Circulation*. 1997;96:2785–2788.
4. Budoff MJ, Oudiz RJ, Zalace CP, Bakshesi H, Goldberg SL, Rami TG, Brundage BH. Intravenous three-dimensional coronary angiography using contrast enhanced electron beam computed tomography. *J Am Coll Cardiol*. 1997;29:393A. Abstract.
5. Chernoff DM, Ritchie CJ, Higgins CB. Evaluation of electron beam CT coronary angiography in healthy subjects. *Am J Radiol*. 1997;169:93–99.
6. Gould RG. Principles of ultrafast computed tomography: historical aspects, mechanisms and scanner characteristics. In: Stanford W, Rumberger JA, eds. *Ultrafast Computed Tomography in Cardiac Imaging: Principles and Practice*. Mt Kisco, NY: Futura; 1993:1–16.
7. Van Ooijen PMA, de Feyter PJ, Oudkerk M. An introduction to three dimensional cardiac image rendering and processing. *Cardiology*. 1997;4:312–319.
8. Ney D, Fishman E, Magid D. Volumetric rendering of computed tomography data: principles and techniques. *Comput Graphics Applications*. 1990;10:24–32.
9. American Heart Association Committee Report. A reporting system on patients evaluated for coronary artery disease. *Circulation*. 1975;51:7–34.