Transthoracic Doppler Echocardiography as a Noninvasive Tool to Assess Coronary Artery Stenoses–A Comparison with Quantitative Coronary Angiography

Markku Saraste, MD, Risto K. Vesalainen, MD, PhD, Antti Ylitalo, MD, PhD, Antti Saraste, MD, PhD, Juha W. Koskenvuo, MD, PhD, Jyri O. Toikka, MD, PhD, Mari-Anne Vaittinen, MD, Jaakko J. Hartiala, MD, PhD, and K. E. Juhani Airaksinen, MD, PhD, *Turku and Pori, Finland*

We prospectively tested the diagnostic accuracy of Doppler transthoracic echocardiography in detection of coronary artery stenoses throughout the main coronary arterial tree. In all, 84 patients referred for diagnostic quantitative coronary angiography were studied. Coronary artery stenosis was identified with color Doppler as local spot of turbulence, and local flow velocity was measured using pulsed wave Doppler. Angiography showed significant stenoses (diameter reduction > 50%) in 33 patients. An abnormal maximal-to-prestenotic blood flow velocity ratio greater than 2.0 in subtotal stenoses, or the detection of collateral blood flow in the absence of normal antegrade flow in the case of total occlusion (N = 6), resulted in overall sensitivity of 82% and specificity of 92%. The sensitivity and specificity were, respectively, 73% and 92% for left anterior descending coronary artery, 63% and 96% for right coronary artery, and 38% and 99% for left circumflex coronary artery stenoses. Transthoracic echocardiography is a promising noninvasive technique to diagnose significant coronary artery stenoses. (J Am Soc Echocardiogr 2005;18:679-85.)

Noninvasive diagnosis of coronary artery disease (CAD) remains an important challenge for clinical cardiology. The development of imaging technology has made it possible to study coronary artery flow noninvasively using Doppler echocardiography. Coronary artery stenoses can be identified by Doppler echocardiography because of turbulent and accelerated flow at the site of stenosis.[1] Stenoses can be assessed invasively by intravascular ultrasound and Doppler wire.[2] Transesophageal echocardiography has also been reported to diagnose stenoses semi-invasively with reasonable accuracy.[3] Previous studies have shown that Doppler transthoracic echocardiography (TTE) can be used to detect restenosis of the left anterior descending coronary artery (LAD) after coronary angioplasty and stenting with good sensitivity and specificity,[4,5] and to quantify the internal thoracic artery graft function after coronary bypass operation.[6] Moreover, total occlusions of the LAD have been detected by retrograde flow in its middle segment.[7] We decided to prospectively assess the accuracy of TTE to detect significant coronary artery stenoses throughout the main coronary arterial tree using quantitative coronary angiography as a reference standard in patients with suggested significant CAD.

From the Departments of Clinical Physiology and Medicine (R.K.V., A.S., M-A.V., K.E.J.A.), Turku University Hospital, and Department of Cardiology, Satakunta Central Hospital (A.Y.).

Reprint requests: Risto K. Vesalainen, MD, PhD, Department of Medicine, Turku University Hospital, Kiinamyllynkatu 4-8, 20520, Turku, Finland (E-mail: *risto.vesalainen@tyks.fi*).

0894-7317/$30.00

doi:10.1016/j.echo.2004.09.016

METHODS

Study Population

We studied 84 consecutive patients (mean age 60 ± 9 years; 50 men) who were referred for diagnostic coronary angiography because of a suggestion of significant CAD. Patients with unstable angina within a week before the study or with a previous myocardial infarction were excluded. The patients continued their usual medication during the study. Exercise testing was performed for 68 patients (81%) as a part of a clinical workup 6 ± 3 months before coronary angiography, but exercise testing was not part of the study protocol. A positive exercise test for CAD according to the definition of American College of Cardiology/American Heart Association guidelines was found in 36 patients (52%).[8] Percutaneous coronary angioplasty was previously performed in two patients but no stents were used. The clinical characteristics and the medications of the study patients are summarized in Table 1. All patients gave written informed consent and the study

Table 1 Clinical characteristics of the study patients (n = 84)

Age (y)	60 ± 9
Body mass index (kg/m^2)	26.8 ± 3.9
Obese (>30 kg/m^2)	15 (18%)
Family history of coronary artery disease*	47 (56%)
Hyperlipidemia†	57 (68%)
Hypertension‡	41 (49%)
Diabetes	8 (10%)
Current smoking	15 (18%)
Peripheral or cerebral arterial disease	5 (6%)
Chronic atrial fibrillation	3 (4%)
Clinical heart failure	9 (11%)
Medication	
β-blocker	57 (68%)
Nitrate	41 (49%)
Calcium channel blocker	13 (15%)
Digoxin	1 (1%)
Angiotensin-converting enzyme inhibitor	13 (15%)
Angiotensin-receptor blocker	8 (10%)
Statin	36 (42%)
Acetosalicylic acid	73 (87%)
Anticoagulant therapy	3 (4%)

*First-degree relatives.
†Serum total cholesterol > 5 mmol/L or low-density lipoprotein cholesterol > 3.5 mmol/L.
‡Blood pressure > 140/90 mm Hg.

protocol was approved by the joint committee on ethics of Turku University and Turku University Central Hospital, Turku, Finland.

Doppler TTE

All patients had a TTE examination a day before the coronary angiography. The same physician (M. S.) carried out all the TTE examinations using ultrasound apparatus (Sequoia C 256, Acuson Inc, Mountain View, Calif) and a standard 3.5-MHz transducer. The mean duration of the TTE study was 52 ± 17 minutes and the mean heart rate during the study was 61 ± 9/min.

We studied anatomic course of the coronary arteries using color Doppler mapping with data postprocessing mix function, which makes the colors transparent. We used all possible standard and nonstandard windows and views to find coronary arteries. The velocity scale of color Doppler was primarily set to 0.24 m/s, but it was changed actively. A 2-dimensional mode image was used to facilitate identification of coronary arteries.

During the TTE examination, we searched the left main coronary artery from the left parasternal short- and long-axis views focusing on area adjacent to the sinus Valsalva cranial to the aortic valve. The proximal LAD continuing from the left main coronary artery and turning slightly toward the transducer was best visualized in the same short-axis view using minor changes of imaging plane. Origin of the first septal branch of the LAD that marks border between the proximal and middle segments of the LAD could be visualized in most patients. We searched the middle and distal LAD from left parasternal windows at varying levels using modified short- and long-axis views focusing on the anterior interventricular sulcus. The segments of the LAD basal and apical to the papillary muscle level in the short-axis view were considered as its middle and distal segments, respectively. The proximal left circumflex coronary artery (LCX) was searched using the left parasternal short- and long-axis views focusing on the atrioventricular sulcus. The part of the LCX that was covered by the auricle of left atrium was considered to represent its proximal segment. We searched the distal LCX using the apical long-axis view focusing to the lateral mitral ring and the 4-chamber view focusing on the inferior mitral ring. The left posterolateral branch of the LCX was visualized using the apical 4-chamber view focusing on epicardial surface of the lateral wall of left ventricle. The ostium and first 2 cm of the right coronary artery (RCA) were seen from the left parasternal short-axis view in the area of right sinus Valsalva cranial to the aortic valve. The rest of the proximal RCA was searched from the right parasternal short- and long-axis views when patients were lying on their right side focusing on the anterior tricuspid ring. The part of the RCA passing anterior surface of the tricuspid ring until the inferior margin of the right ventricle was considered as the proximal segment of the RCA. The middle RCA was visualized from the subcostal short-axis view focusing to the medial tricuspid ring on the inferior surface of the heart. The distal RCA was visualized using the subcostal 4-chamber view focusing to the posterior tricuspid ring. Finally, the posterior descending artery in the posterior interventricular sulcus coursing toward the apex of the heart was visualized from the apical 2-chamber view.

Coronary artery stenosis was identified as localized color aliasing indicating local acceleration and as turbulence of flow. Normal coronary artery flow is slow and laminar and causes a weak Doppler signal. In contrast, turbulent and accelerated flow at the site of stenosis causes strong signal. To assess severity of the stenoses we quantified flow acceleration as ratio of maximal flow velocity at the site of aliasing to nearest upstream nonaccelerated prestenotic flow velocity (Figure 1). Blood flow velocity was measured at the beginning of diastole using pulsed wave Doppler with 2-MHz frequency in an average sample volume of 5 mm. Multiple consecutive cardiac cycles were analyzed to find average flow velocity. During measurements, the angle between flow and Doppler beam was kept as small as possible and angle correction was always used. In some coronary segments, such as the proximal RCA or distal LCX, it was sometimes impossible to optimize the angle because of horizontal course of the coronary artery. In these segments, stenotic flow velocity was approximated using rescaling of color Doppler. Prestenotic flow velocity was measured with pulsed wave Doppler from nearest possible upstream flow. A predefined maximal-to-prestenotic ratio more than 2 was used as a cut-off value for significant stenosis.[9]

To detect total coronary occlusion by TTE, we analyzed flow in the septal branches of the LAD from left parasternal short-axis views using color Doppler. Normally, we