Visualization of Coronary Blood Flow by Color Doppler Imaging with a Transesophageal Approach*


To examine whether CBF can be imaged by color Doppler technique, we visualized CBF using a transesophageal color Doppler imaging system. In 36 of 39 patients with normal coronary arteriograms after heart surgery, the LMT and the proximal LAD were clearly imaged by 2-dimensional echocardiography. Among them, CBF was coded mainly in blue in 32 patients, showing that the flow runs from proximal to distal. In some cases, yellowish and/or reddish components were seen, suggesting the occurrence of aliasing associated with augmentation of flow velocity or flow turbulence. The fast Fourier transformation spectrogram of the pulsed Doppler sampled in the colored flow showed a typical flow velocity pattern of the LAD, which mainly consisted of a predominantly diastolic component. These results indicate that the transesophageal color Doppler technique is advantageous in noninvasively imaging CBF. It should be further sought whether flow abnormality due to coronary stenosis could be determined by this technique.

\[ \text{CBF = coronary blood flow; LAD = left anterior descending artery; LMT = left main trunk} \]

Intrastaneous estimation of coronary flow dynamics by Doppler technique may provide pivotal information about the pathophysiologic condition of coronary circulation. For this purpose, the detection of CBF has been attempted by several authors, who showed that the LAD flow was detectable by the conventional continuous wave or pulsed Doppler technique from a transthoracic approach.\(^1,2\) However, the ability to detect CBF by these techniques has not been satisfactory because of the technical difficulties in detecting blood flow through the moving coronary lumina during the cardiac cycle. Transesophageal Doppler echocardiography, originally performed to detect transmital valve flow,\(^4\) has enabled us to visualize the coronary artery and to detect its blood flow effectively.\(^5\) We previously reported that the LAD flow was highly detectable by the transesophageal 2-dimensional pulsed Doppler echocardiography,\(^6\) indicating that the transesophageal approach was useful in evaluating coronary hemodynamics noninvasively.

In that study, however, real-time visualization of CBF, which may contribute to recognition of coronary flow disorder, was still impossible. If such an instantaneous CBF imaging is possible, CBF abnormality due to the existence of stenosis may be diagnosed noninvasively. Color Doppler flow imaging technique, which was applied to image the intracardiac blood flow,\(^7\) may be applicable to visualize CBF in real-time when combined with the transesophageal technique. In the present study, we attempted to visualize CBF by the transesophageal color Doppler flow imaging technique for the first step.

**Materials and Methods**

**Study Patients**

We studied 39 patients, 22 men and 17 women, aged 28 to 58 years, with an average of 54 years, in the ICU after heart surgery. Thirty-four patients had had valvular replacement and five repair of congenital heart disease. All patients were intubated and put on controlled respiration. Coronary angiography performed before surgery had not demonstrated significant organic lesions in any patients. None of the patients had a history of swallowing problems or esophageal disease. These patients were put on the echocardiographic monitoring to evaluate their cardiac conditions such as ventricular dimension or intracardiac flow velocity. We used the transesophageal approach because the precordial approach had not been available due to surgical chest wounds.

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After the color Doppler examination, the sample volume of the pulsed Doppler was set at the center of color flow images of the LAD to document the time sequential flow patterns of the visualized flow images. The characteristic velocity pattern of visualized flow helped to confirm whether the visualized color flow images actually represented the LAD flow.

We also attempted to visualize the right coronary flow, although the earlier study had indicated that the Doppler signals from the right coronary artery were not stable compared with those from the LAD. Color flow images were recorded on photofilms, and the flow velocity pattern by pulsed Doppler was recorded on photofilms or strip chart recorder.

RESULTS

The echocardiographic image of the proximal left coronary artery including the LMT and/or the proximal LAD was obtained in 36 of the 39 patients examined. The color flow signal was obtained in the LMT as well as in the LAD when the cross-sectional plane could be fixed to a proper angle between the Doppler beam and the flow. In 32 of 36 patients, the color images of the LMT or the proximal LAD flow were represented by bluish jets, indicating a flow running from proximal to distal along the lumen (Fig 1 and 2). However, it was difficult to obtain color flow signals from the circumflex artery even if this artery was imaged in the 2-dimensional echocardiogram, possibly owing to an improper angle between the

FIGURE 1. Representative pattern of color Doppler flow image of blood flow in the left main trunk (LMT). When the probe was fixed to visualize the LMT as long as possible, blood flow from the coronary orifice to the left anterior descending artery through LMT was imaged (arrows). The flow running through the left coronary ostium into the artery is imaged in red; that in the LMT in blue. AO = aorta, LA = left atrium.

Doppler Equipment

The transesophageal Doppler probe, a commercially available gastrofiberscope of 9.8 mm in diameter with a 3.75-MHz phased-array transducer placed at the tip, was connected to the color Doppler imaging system (SSH-65A, Toshiba). The pulse repetition rate was 4 kHz or 6 kHz, and the scanning plane was transverse to the axis of the fiberscope. In this system, the conventional pulsed Doppler system was also available to assess flow velocity at the sample volume with the fast Fourier transformation analysis. The flow directed toward the esophageal transducer was coded in red and that away from the transducer in blue, the same as in the conventional transthoracic color Doppler system.

Visualization of Coronary Flow

Informed consent was obtained from all patients before surgery. After measurement of chamber dimensions or transvalvular flow, CBF was detected by the method previously reported in detail. Briefly, after insertion of the Doppler probe into the esophagus, the position of the transducer was carefully monitored by the 2-dimensional echocardiographic image. At the level where the aortic valve was imaged, we examined the existence of the left coronary artery by shifting the probe upward with a counterclockwise rotation. When the LMT and/or the proximal LAD were found, the best position of the transducer was chosen for visualizing these arteries as long as possible. Under these conditions, the left circumflex artery was sometimes seen in the same plane. Color Doppler images of CBF were recorded at the position where they were maximally obtained.

FIGURE 2. Representative pattern of color Doppler flow image of blood flow in the left anterior descending artery (LAD). After slight counterclockwise rotation to visualize the LAD, the bluish LAD flow was documented (arrow). AO = aorta, LA = left atrium.
beam and the flow.

Pulsed Doppler signals from the sample volume at the center of the LAD flow images indicated characteristic velocity patterns, which consisted of major diastolic and preceding small systolic components (Fig 3). These flow patterns appeared to be compatible with those of the LAD, which were determined by other invasive and noninvasive methods, indicating the reliability of the ultrasound methods, including the present transesophageal approach.

Although the blood flow of the proximal LAD was usually recognized as bluish, in five of the 32 patients there were yellowish or reddish components producing a mosaic-like pattern with the original bluish components (Fig 4). Under these conditions, pulsed Doppler technique demonstrated slight augmentation of flow velocity. In the remaining four of the 36 patients, clear color flow images were not obtained, although the pulsed Doppler technique revealed the coronary flow signal in the proximal LAD, which could be imaged by the 2-dimensional echocardiography.

The right coronary flow was recognized in only five patients in whom blood flow at the orifice was seen as a bluish flow image; however, it was difficult to follow the flow image distally along the coronary lumen.

During the procedures, there were no serious complications such as esophageal damage or hemodynamic alterations.

**DISCUSSION**

Noninvasive assessment of CBF has been made by several authors who showed that the left coronary flow was detectable by the continuous wave or pulsed Doppler techniques using the transthoracic approach. However, there remain technical difficulties in detecting CBF from the chest wall, thus resulting in relatively low detection ability in these studies. Some of us have reported that in only 50 percent of patients examined was the left coronary flow detectable by the pulsed Doppler technique from the transthoracic approach.

The Doppler echocardiographic technique from the transesophageal approach has enabled us to visualize the left coronary artery and to detect its flow more effectively; obstructive lesions of the LMT or the right main trunk might be detectable by the transesophageal 2-dimensional echocardiography, as suggested by Schnittger et al. We previously reported that a typical flow velocity pattern of the proximal LAD and the right coronary artery was obtained by the transesophageal pulsed Doppler technique, suggesting the advantage of this approach for noninvasive assessment of the coronary flow dynamics. The color Doppler flow imaging technique may also be advantageous in visualizing CBF in real time when combined with the transesophageal approach.

In the present study, color images of the LMT or proximal LAD flow were clearly obtained in 32 of 36 patients in whom 2-dimensional echocardiographic images of these arteries were obtained. The velocity
spectrograms of these color flow images demonstrated the same pattern as determined by conventional pulsed Doppler echocardiography.\textsuperscript{2,3} In general, it is possible that, in the conventional pulsed Doppler technique, the sampling site in the coronary lumen is contaminated by some other surrounding flows with high power output, such as pulmonary regurgitant flow in diastole. However, the present results clearly showed that the above-mentioned pattern is limited within the LMT or LAD lumen, so that they appeared to verify the previous interpretations that this flow velocity pattern originated from the LMT or the proximal LAD. This is one of the advantages of the color flow imaging over the conventional pulsed Doppler technique.

Although the LAD flow was generally visualized in blue, representing the blood flow away from the transducer, some patients exhibited color flow images of mosaic-like pattern that consisted of bluish, yellowish, and reddish components. The appearance of such a mosaic-like pattern may be related to the occurrence of aliasing or flow turbulence.\textsuperscript{7} As we did not attempt to increase the pulse repetition rate of the color Doppler images to distinguish aliasing due to high flow velocity from flow turbulence, it remains unclear whether the observed mosaic-like pattern was due to the actual aliasing associated with the presence of high flow velocity. However, the finding that flow velocity was slightly augmented at this site suggests that the visualization of the mosaic-like image may indicate augmentation of CBF velocity. It should be further examined whether actual flow turbulence may also induce the mosaic-like flow pattern in the coronary circulation.

Clinical Implications

It is intriguing to speculate whether the mosaic-like flow images observed in the present study indicate an accelerated flow through a stenosis at the same site, although we did not examine this procedure in patients with coronary artery disease. If there were a specific finding of color flow images representing a stenotic lesion, one might predict the existence of coronary stenosis noninvasively by showing such a mosaic-like pattern in the coronary artery.

Problems and Limitations

We demonstrated that the LMT and/or proximal LAD flow was visualized by the present system. There remain, however, problems to be resolved. First, sometimes CBF was not imaged, although the coronary lumen is well observed in the 2-dimensional echocardiography. This may mainly result from the current specifications of the color Doppler system (SSH-65A, Toshiba) which were designed to be convenient for visualizing intracardiac flows, so that flow velocity less than 15 cm/s is not encoded in color. The CBF is considered to be generally slower than the intracardiac flow and the aortic flow according to information obtained by other methods,\textsuperscript{4,5,6} although color encoding depends not only on flow velocity but also on flow dimensions.\textsuperscript{9} Improvement of sensitivity in the color Doppler system will be required to overcome these shortcomings.

In addition, the color flow imaging was limited to the LMT and/or the proximal portion of the LAD. It is still difficult to detect the blood flow in the distal portion of the LAD as well as the right coronary artery where these arteries run downward along the interventricular sulcus (LAD) or atrioventricular sulcus (right coronary artery), because the scanning plane of the present system is fixed, transverse to the axis of fiberscope. For the distal part of the LAD or the right coronary artery, it will be advantageous to set the scanning plane parallel to the axis of the transesophageal probe. Further improvement of transesophageal Doppler probe may overcome these shortcomings to visualize coronary flow effectively.

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