Novel Application of Tissue Doppler Imaging:

A Preliminary Observational Study

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Tissue Doppler imaging was used with transthoracic and transesophageal echocardiography to determine its clinical usefulness beyond visualization of ventricular wall motion. Thirteen novel applications were found: acoustically difficult transthoracic studies, thrombus, mitral chordal motion, shunt detection using saline contrast, spontaneous echo contrast, intra-aortic balloon pump position and function, endocarditis (prosthetic and native), valve strands (prosthetic and native), mobile aortic atheroma, prosthetic valve motion, aortic valve motion in the presence of a calcified aortic annulus, systolic anterior motion of the mitral valve, and cardiac tumors. Tissue Doppler imaging directly affected the ability to make difficult diagnostic decisions with increased confidence and reduced the need for additional studies. (ECHOCARDIOGRAPHY, Volume 15, August 1998)

tissue Doppler imaging, tissue Doppler echocardiography

The concept of tissue Doppler imaging (TDI) has evolved from ultrasound and Doppler imaging. The technique was specifically developed to allow color Doppler imaging of myocardial wall motion rather than blood pool imaging.[1,2] The principle of TDI takes advantage of the different Doppler characteristics of ventricular wall motion versus blood flow. Wall motion velocity is substantially lower, ~5–10 cm/sec, compared with ~50–100 cm/sec for blood flow. In addition, the amplitude of the Doppler signal from ventricular wall motion is ~40 dB higher (100 times greater) than that of the blood flow Doppler signal. A conventional color flow Doppler imaging system must use a high pass filter to remove low velocity Doppler signals from cardiac wall motion to calculate blood flow velocity. The computer software then processes the filtered information, yielding Doppler mean velocity and variance data. In TDI, however, the high pass filter is eliminated and the Doppler data are input directly for computer processing. For both conventional color Doppler imaging and TDI, the computer uses autocorrelation processing techniques. Unlike conventional color Doppler blood flow imaging, TDI displays only low velocity components with full-scale color brightness and hue by enhancing the ability of the velocity calculation unit to measure low velocity flows. This allows for the detection of low tissue velocities using high speed sector scanning, which makes it easier to identify changes in systolic and diastolic velocities and to assess asynchrony of the ventricular myocardium.[3]

This technology has been used to determine the range of mean myocardial velocities in normal subjects,[4] as well as to evaluate systolic and diastolic myocardial motion. Studies comparing conventional M-mode echocardiography with TDI to evaluate wall motion velocity in patients with normal and diseased hearts have shown good correlation.[5] Other studies have quantitatively assessed left ventricular contraction through the use of the myocardial velocity gradient with quantitative velocity data from the endocardium and epicardium to help

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overcome the limitations of whole-heart motion.[6] The ability to use color-coded velocity data to quantify alterations in regional left ventricular contractility and function in patients with heart disease has also been demonstrated.[7,8] When used in conjunction with dobutamine stress echocardiography, TDI can improve detection of wall motion abnormalities, helping clinicians distinguish abnormal from normal left ventricular wall motion.[9,10]

Moreover, measurement of peak mitral annular descent velocity with TDI has the potential to rapidly estimate global left ventricular function.[11] TDI technology has been used to calculate cardiac wall velocities in patients with coronary artery disease and varying cardiomyopathies. It also has been successful in identifying sites of abnormal electrical activation in patients with the Wolff-Parkinson-White syndrome and in determining the origin site of ventricular tachycardia. The potential for TDI technology to enhance visualization of high amplitude signals with relatively low velocities suggests that the motion of valve strands, thrombi, atheroma, mitral chordae, and vegetation would be enhanced as well (Table I).

The objectives of the present study were to determine how well a previously unseen or poorly defined cardiac structure could be visualized with TDI and to determine whether the visualization of structures with conventional echocardiographic techniques could be enhanced to provide additional information to help confirm a diagnosis or refine treatment strategies.

TABLE I

Novel Applications of TDI

1. Acoustically difficult transthoracic studies
2. Valve strands (prosthetic, native)
3. Aortic atheroma
4. Spontaneous echo contrast
5. Saline contrast for shunt detection
6. Thrombus
7. Diagnosis of endocarditis (prosthetic, native)
8. Mitral chordal motion
9. Systolic anterior motion of the mitral valve
10. Identification of normal aortic valve motion (calcified aortic annulus)
11. Prosthetic valve motion
12. Cardiac tumors
13. Proper IABP position and function

TDI = tissue Doppler imaging; IABP = intra-aortic balloon pump.

Methods

Echocardiographic and transesophageal echocardiography (TEE) studies with TDI were conducted as a routine part of echocardiographic studies in consecutive hospitalized and nonhospitalized patients from 1994 to the present (Toshiba PowerVision Ultrasound System; Toshiba America Medical Systems, Tustin, CA, USA). A 2.5-MHz probe was used in all thoracic studies; a 5.0-MHz transducer was used in all TEE examinations. The pulse repetition frequency was 4.5 kHz for all studies. Most objects of interest are of relatively low velocity. It was found that relatively low TDI ranges yielded the best visualization. Velocity ranges of 2.88–5.76 cm/sec for TDI were found to optimally differentiate the motion of objects of interest from surrounding tissue. A nondirectional color velocity map was used in several cases because of its ability to display small velocity differences with additional colors. The velocity range was increased to 8.64 cm/sec to image higher velocity structures such as mechanical valve leaflets.

Results

As expected, the addition of TDI to transthoracic echocardiographic (TTE) and TEE studies did improve the assessment of ventricular wall motion. It became readily apparent, however, that the use of TDI also enhanced visualization of other cardiac structures, thereby making it possible to form diagnostic impressions with greater confidence and precision in some cases and leading to modifications in clinical management in other cases. To the author's knowledge, the novel TDI applications outlined in Table I have not been reported previously.

Acoustically Difficult Transthoracic Study

TDI has been helpful in situations in which TTE was acoustically difficult. A 70-year-old man presented with hypotension and a new

murmur. He was 3 weeks status postcoronary artery bypass graft surgery. Although the left ventricle could not be adequately imaged, the application of TDI demonstrated abnormal systolic anterior motion (SAM) of the mitral valve from an apical window (Fig. 1). The diagnosis was subsequently confirmed by TEE (Fig. 2).

Ruptured Mitral Chordae

Another patient presented with significant mitral regurgitation. During the preoperative TEE examination, TDI highlighted a small ruptured mitral chorda that had not been previously seen (Fig. 3). The enhanced visualization better delineated mitral anatomy in preparation for surgery.

Visualization of Prosthetic and Native Valve Strands

Visualization of native and prosthetic heart valve strands can assist physicians in making accurate diagnoses. TDI performed in conjunction with TEE facilitated strand detection and enhanced the visibility (Figs. 4 and 5). The ability to rapidly detect valvular strands with better visualization compared with conventional imaging may affect the management of patients with arterial embolism.

Improved Identification of Mobile Aortic Atheromas

The identification of aortic atheroma, especially mobile atheroma, was another area in which TDI proved to be helpful. TDI easily differentiated mobile from nonmobile atheroma, quickly helping to classify those that were more likely to be clinically relevant. TDI in the descending aorta is illustrated in Figures 6 and 7. Figure 8 depicts TEE with TDI of the descending aorta, highlighting a highly mobile filamentous strand that was seen without TDI only after first being identified using TDI.

Identification of Thrombus

TDI was valuable in identifying "independent" motion of thrombus. A 19-year-old woman with respiratory and hemodynamic collapse underwent a TTE study (she did not have a central line placed). Although a thromboembolus was suspected in the right pulmonary artery (RPA) during imaging from the suprasternal notch, TDI dramatically highlighted its independent motion, helping to confirm the diagnosis and eliminating the need to perform additional procedures. An M-mode TDI color map through the thrombus revealed its motion independent of the pulmonary artery wall (Figs. 9–11). Similarly, a 54-year-old man with a recent anterior myocardial infarction underwent TTE. In the apical four-chamber view, a left ventricular apical thrombus was seen (Fig. 12). B-tint imaging improved thrombus delineation (Fig. 13), and two–dimensional (2-D) TDI (Fig. 14) demonstrated its mobility independent of the motion of the left ventricle.

Identification of Prosthetic and Native Valve Motion

The ability to color code valve opening and closing velocities (Fig. 15) made TDI useful for the evaluation of prosthetic valve motion and function. A 72-year-old patient with a systolic murmur underwent echocardiography for possible aortic stenosis. The patient had heavy calcification of the aortic annulus and inadequate visualization of leaflet mobility. TDI revealed excellent aortic valve motion (Fig. 16). Fine systolic fluttering of the nonstenotic valve was also clearly demonstrated (Fig. 17), thereby helping avoid the necessity of further aortic valve studies.

Monitoring Intra-Aortic Balloon Pump Placement and Function

TEE with TDI proved to be useful for visualization of the tip of an intra-aortic balloon pump (IABP) within the lumen of the aorta and at the proper level (Fig. 18). M-mode TDI demonstrated proper balloon inflation and deflation (Fig. 19).

Infective Endocarditis

A patient with a Carpentier-Edwards bioprosthetic aortic valve replacement was evaluated for possible endocarditis after presenting

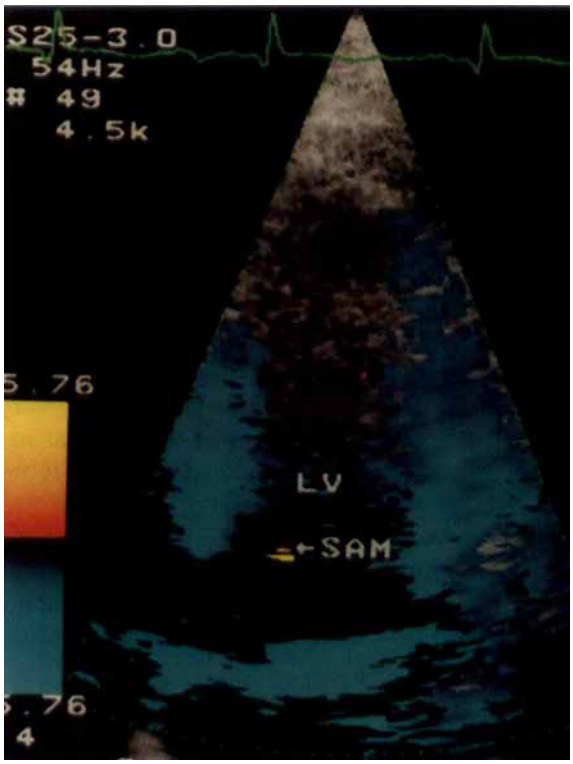

Figure 1.

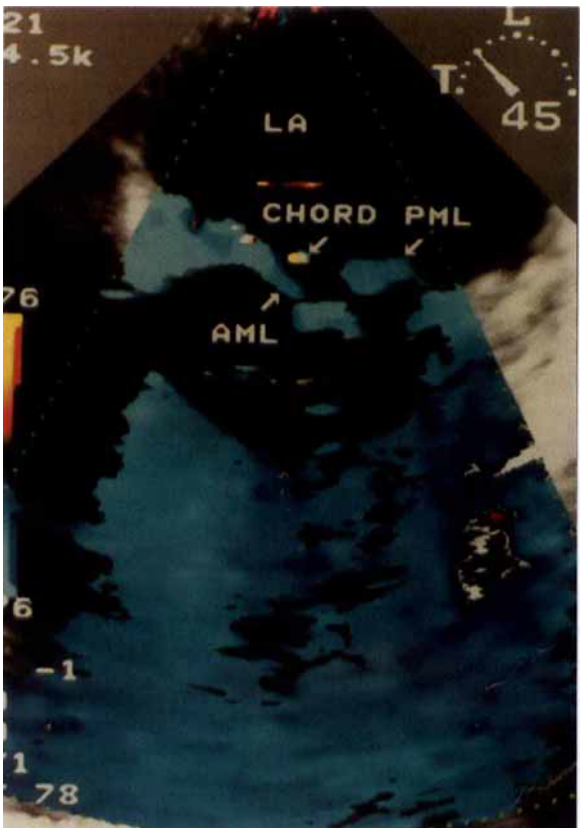

Figure 3.

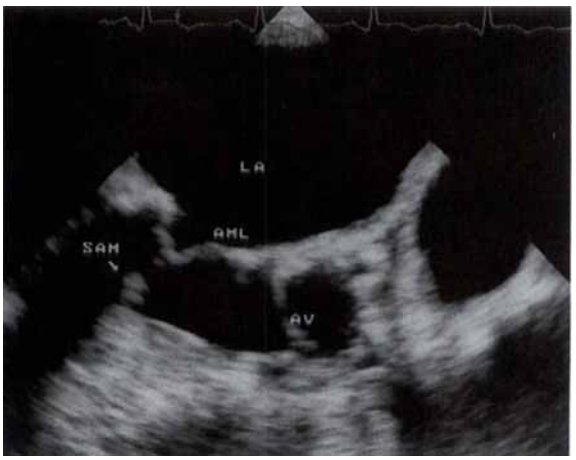

Figure 2.

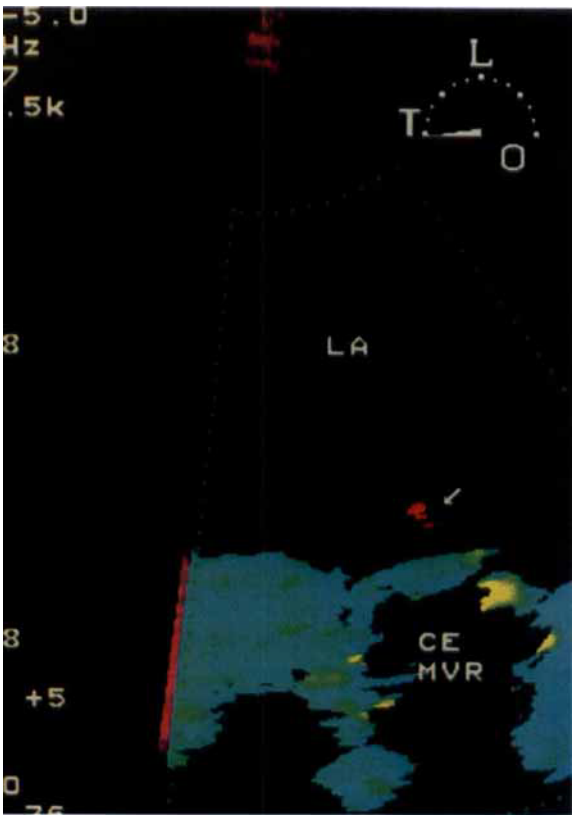

Figure 4.

Figure 1. *Tissue Doppler imaging (TDI) demonstrates abnormal systolic anterior motion (SAM) of the mitral valve from an apical window (velocity range, ~5.76 cm/sec).*

Figure 2. *Transesophageal echocardiography (TEE) confirms presence of systolic anterior motion (SAM) with outflow obstruction in the same patient. AML = anterior mitral valve; AV = aortic valve; LA = left atrium.*

Figure 5.

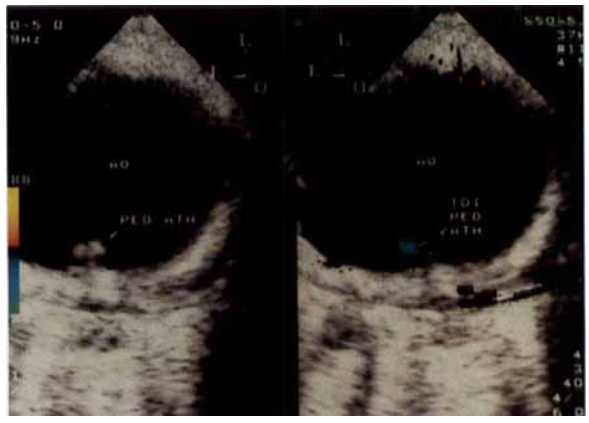

Figure 6.

Figure 7.

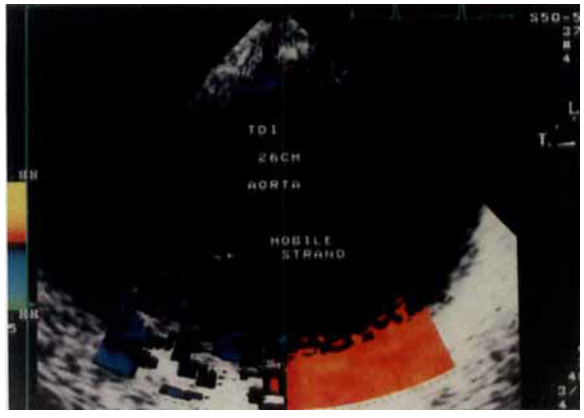

Figure 8.

Figure 3. *Tissue Doppler imaging (TDI) highlights a ruptured mitral chorda during a preoperative transesophageal echocardiography (TEE) examination for mitral valve repair (velocity range, 5.76 cm/sec). AML = anterior mitral valve leaflet; LA = left atrium; PML = posterior mitral valve leaflet.*

Figure 4. *Tissue Doppler imaging (TDI) demonstrates a valve strand (arrow) attached to a Carpentier-Edwards mitral valve prosthesis. Bright color indicates high mobility (velocity range, 2.88 cm/sec; nondirectional color velocity map).*

Figure 5. *Tissue Doppler imaging (TDI) and B-tint demonstrate a valve strand attached to a St. Jude mitral valve prosthesis. Bright color indicates high mobility (velocity range, 5.76 cm/sec; nondirectional color velocity map).*

Figure 6. *(Left) Image demonstrates a pedunculated atheroma. (Right) Mobility is enhanced with tissue Doppler imaging (TDI). (Velocity range, 2.88 cm/sec.)*

Figure 7. *(Left) M-mode tissue Doppler imaging (TDI) highlights a mobile pedunculated atheroma. (Right) Same atheroma in two dimensions. (Velocity range, 2.88 cm/sec.)*

Figure 8. *Tissue Doppler imaging (TDI) highlights a highly mobile filamentous strand (arrow) (velocity range, 2.88 cm/sec).*

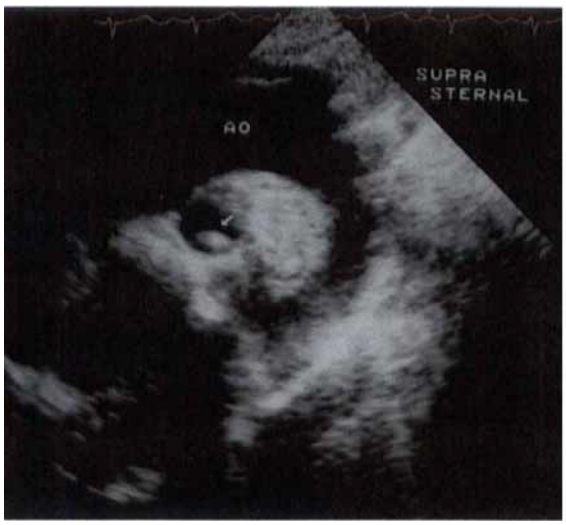

Figure 9.

Figure 10.

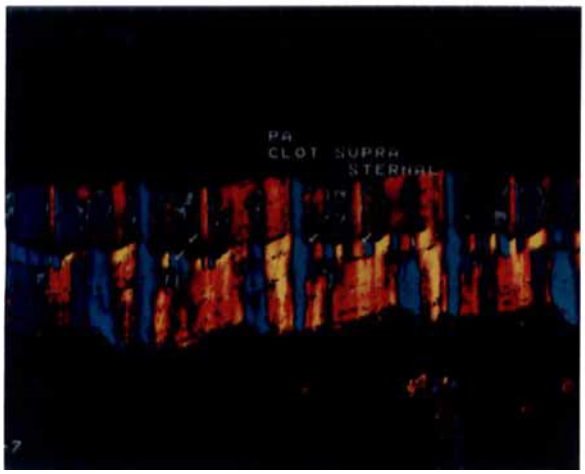

Figure 11.

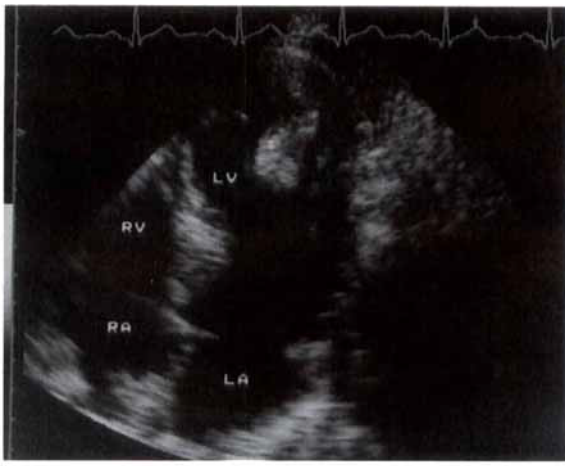

Figure 12.

Figure 9. *Arrow points to a suspected thrombus in the right pulmonary artery (RPA).*

Figure 10. *Two-dimensional tissue Doppler imaging (TDI) reveals "independent" motion of the thrombus from the right pulmonary artery (RPA) (velocity range, 5.76 cm/sec).*

Figure 11. *M-mode tissue Doppler imaging (TDI) demonstrates the independent motion of thrombus (arrows) (velocity range, 5.76 cm/sec).*

Figure 12. *Apical four-chamber imaging demonstrates a left ventricular apical thrombus in a 54-year-old man.*

Figure 13. *B-tint imaging improves thrombus delineation.*

Figure 14. *Two-dimensional tissue Doppler imaging (TDI) demonstrates thrombus mobility independent of left ventricular motion (velocity range, 5.76 cm/sec).*

Figure 15. *M-mode tissue Doppler imaging (TDI) of a St. Jude mitral valve replacement demonstrates normal high-velocity valve opening and closing (velocity range, 8.64 cm/sec; nondirectional color velocity map).*

Figure 16. *Two-dimensional image demonstrates excellent aortic valve motion (velocity range, 5.76 cm/sec).*

Figure 17. *M-mode tissue Doppler imaging (TDI) demonstrates fine systolic fluttering of the nonstenotic valve (velocity range, 5.76 cm/sec).*

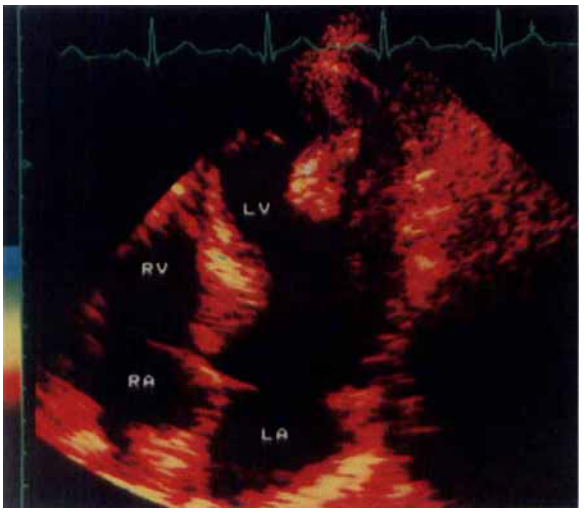

Figure 13.

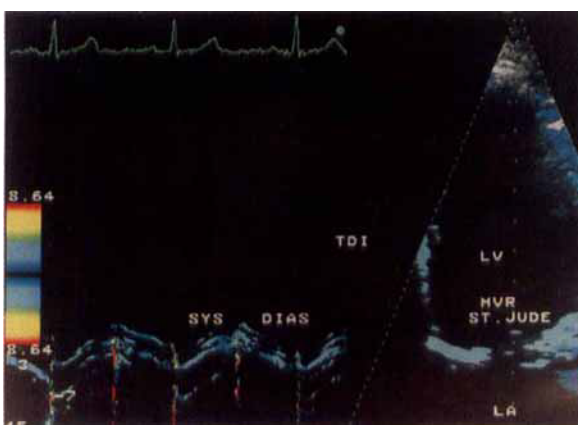

Figure 15.

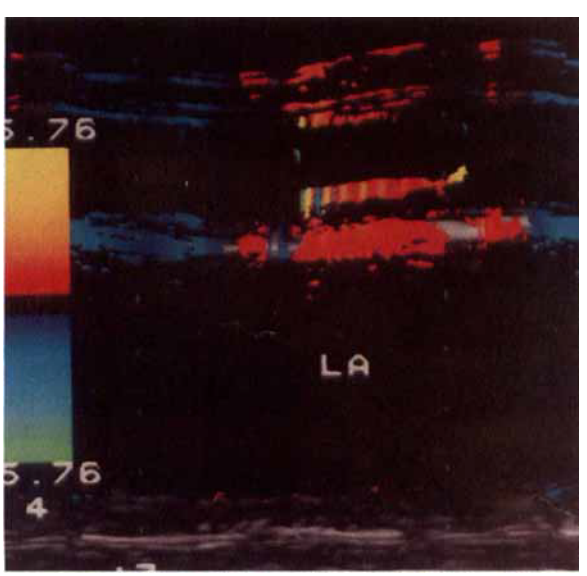

Figure 17.

Figure 14.

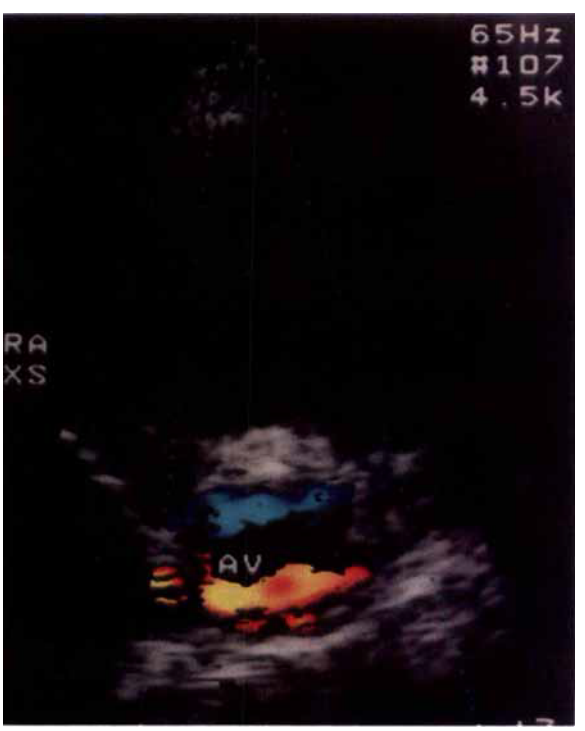

Figure 16.

Figure 18. *The tip of an intra-aortic balloon pump (IABP) is clearly demonstrated with tissue Doppler imaging (TDI) (velocity range, 5.76 cm/sec).*

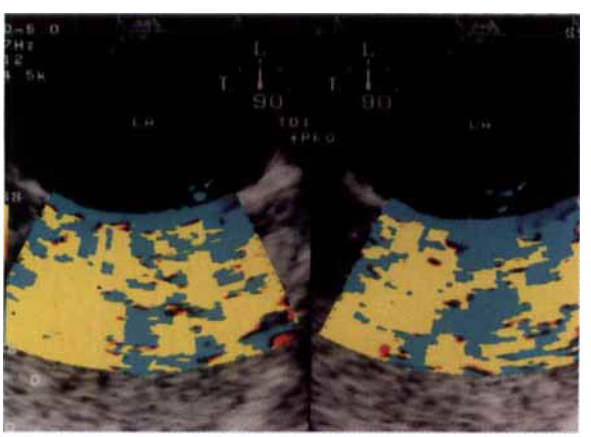

Figure 20. *Tissue Doppler imaging (TDI) enhances peripheral saline contrast injection of a small right-to-left shunt through a patent foramen ovale (PFO). Arrows indicate the presence of microbubbles in the left atrium (LA). (Velocity range, 2.88 cm/sec.)*

with fever and positive blood cultures for *Streptococcus viridans*. Although TEE was unremarkable, TDI demonstrated a small vegetation on a valve leaflet, which confirmed the diagnosis of endocarditis. The finding made it possible to immediately initiate therapy.

Enhanced Imaging of Saline Contrast

TDI enhanced the quality of intravenous contrast studies by improving the visualization of contrast bubbles. This proved to be helpful

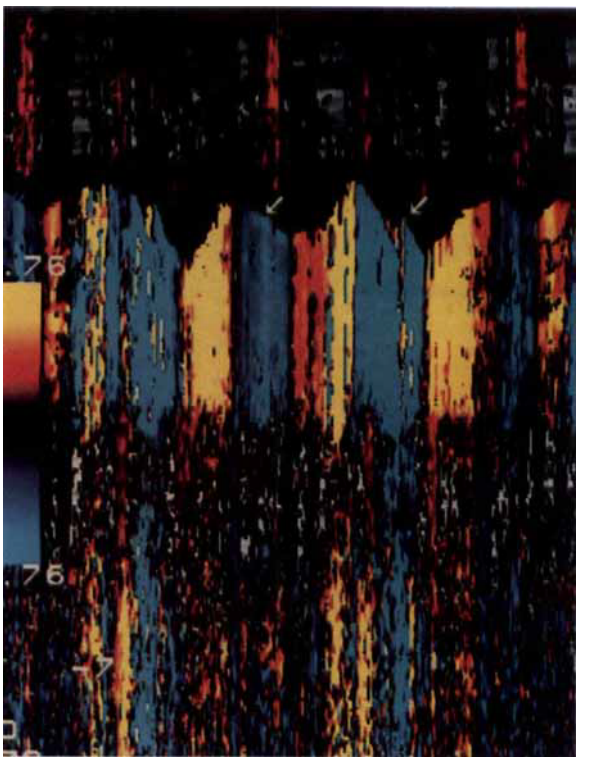

Figure 19. *M-mode tissue Doppler imaging (TDI) demonstrates the motion of intra-aortic balloon pump (IABP) inflation and deflation (velocity range, 5.76 cm/sec).*

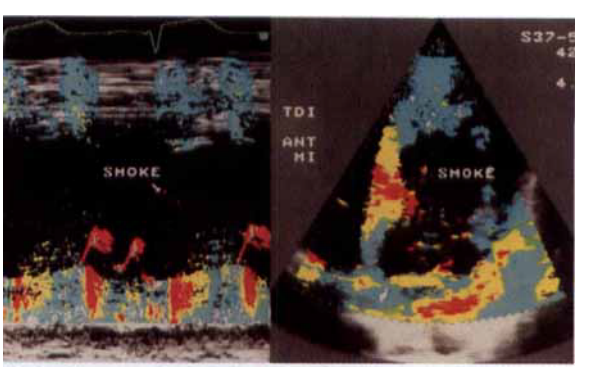

Figure 21. *Apical four-chamber view with tissue Doppler imaging (TDI) enhanced imaging of spontaneous echo contrast. (Left) M-mode image through the left ventricle. (Right) Two-dimensional image on the right. (Velocity range, 3.55 cm/sec; nondirectional color velocity map.)*

in patients with relatively small atrial level shunts, such as when few bubbles traverse the atrial septum. Diagnoses were made with

greater confidence and fewer contrast injections. Figure 20 shows the sequential frames of a TEE study at the level of the atrial septum at 90°. Contrast is better visualized in the left atrium, having passed from the right atrium through a patent foramen ovale.

Improved Spontaneous Echo Contrast Visualization

TDI also improved the visualization of spontaneous echo contrast ("smoke") in the left atrium with TEE and in the left ventricle with TTE (Fig. 21). This may affect the decision-making process when evaluating a patient for the source of embolism.

Discussion

By improving the visualization of moving tissue, TDI has the potential to improve the imaging of specific abnormalities, as well as that of normal anatomy and function. TDI facilitated the visualization of structures that were not previously seen or could not be confidently identified. In our laboratory, heart and aorta abnormalities have been identified within less time and with greater certainty than with the use of TTE and TEE alone. This preliminary observational study suggests that TDI may be useful for applications such as acoustically difficult transthoracic studies and the imaging of ruptured mitral valve chordae, mobile aortic atheroma, valve strands, thrombi, vegetation, native and prosthetic heart valves, and other clinically relevant structures. Clinically, TDI allowed difficult diagnostic decisions to be made with greater confidence and helped reduce the need to conduct additional evaluations.

Study Limitations

This is an anecdotal observational study and not a prospective comparison of traditional echocardiographic technique with TDI. Further studies are needed to determine the potential value of TDI for diagnosis and delineation of small, mobile cardiac structures.

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