Tissue Doppler Imaging

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Echocardiography is now the method more commonly used for assessment of diastolic function. In addition to high-resolution 2-D images, Doppler flow velocity offers important information about the dynamics of ventricular filling. Pulsed wave Doppler of the mitral and pulmonary veins is used for routine assessment of left ventricular diastolic function. Similarly, Doppler flow of the tricuspid and hepatic veins is used to evaluate right ventricular diastolic function [1].

An important limitation of the spectral Doppler assessment of diastolic function is its dependence of loading conditions. With worsening left ventricular diastolic function there is a compensatory increase in left atrial pressure, increase in the velocity of the E wave of the mitral inflow and pseudo normalization of the filling pattern (normal E/A ratio and deceleration time), TDI can differentiate in this case between normal and pseudo normal pattern [2].

Recently, 2 new technologies, color M-mode and Doppler Tissue echocardiography, have emerged that are very promising in complementing the information provided by Doppler echocardiography and may allow us a more complete evaluation of diastolic function [3].

Principle of TDI

Tissue Doppler scanner is operated in a similar way to conventional ones. Most of the system parameters and their effects on the image are exactly the same, as: - [4]

Frame rate/Field of view: The frame rate is indirectly controlled through the definition of the region of interest. The framing rate is an important factor in determining the acceptability of 2-D cardiac images. In conventional color Doppler flow imaging systems, the" frame rate is usually set 10 frames/second with pulse repetition frequency of 4.5 KHz. However, under these conditions, a time lag can occur between the beginning and the end of the scanning of one frame and 100 ms is needed, which was provided an insufficient temporal resolution in TDI for accurate depiction of each phase of myocardial motion [5]. For one frame to be completed and starting another frame, it is possible to reduce the time lag for each frame thus allowing increasing the framing rate. In TDI, the numbers of data samples were reduced to half that of the conventional color flow imaging system. The pitch of the scanning line was also expanded to 1.5 times that of the conventional system. All these modifications allowed the use of smaller packet sizes and higher pulse repetition frequencies that resulted in framing rate up to three times that of the conventional color flow.

Gate Size: Increasing the gate size will lead to increase sensitivity (the ability to detect moving tissue) but with decreased spatial resolution due to a higher sample volume size [6].

Gain setting: In TDI system three gain settings interact to produce the image, the gray scale-depth adjustable gain, the Doppler gain and the TDI gain. The relative amount of gray 2D and color information depend on all these sittings. To increase the amount of color it is necessary to increase the Doppler gains or to decrease the (global or regional) 2D gain. Incorrect sittings may produce poorly colored or saturated images [7].

Scale: The range may be selected to display the lower and higher velocities. As in conventional Doppler imaging, the most expanded but still aliasing-free scale should be selected.

Color map: Usually the color defines the direction however color saturation and or hue indicates the velocity of the motion. Many different color maps exist, they may be liner or non-liner, and even a given interval may be selected for tagging a different color.

Persistence: The image may be either temporally or spatially smoothed to produce better looking of the image.

Low velocity filtering: Lowest velocity signals can be rejected, thus improving the signal to noise ratio.

Threshold filter: It allows the exclusion of the weakest signals, which may be largely noisy.

Transmitter power: Color Doppler and 2D power may be independently set in some systems.

All these sittings and some others contribute to image quality and interact with each other. These parameters must be adjustable so that we can obtain the optimal image quality. Also tissue Doppler shares the same limitation that of flow Doppler, the most important of which is angle dependence. But there are two major differences between the acoustic characteristics of Doppler signals from the cardiac wall and those from blood flow [8]:

Wall motion velocity is much slower than blood flow velocity (usually 10 cm/s) whereas blood flow velocity in the ventricular cavity is approximately (10-100 cm/s).

Doppler signal intensity of wall motion is much greater (about 40 db) than that of Doppler signal coming mainly from red blood cells, so it is possible to obtain images of tissue Doppler motion of high resolution without significant artifact originating from blood pool. In such images, each pixel displays one color representing a mean velocity value [9].

Doppler echocardiography relies on detection of the shift in frequency of ultrasound signals reflected from moving objects. With this principle, conventional Doppler techniques assess the velocity of blood flow by measuring high-frequency, low-amplitude signals from small, fast-moving blood cells. In TDI, the same Doppler principles are used to quantify the higher-amplitude, lower-velocity signals of myocardial tissue motion [5].

In a conventional Doppler system a high pass filter is incorporated to eliminate these low velocity signals and the gain settings are increased to amplify the signals reflected by moving blood. To display tissue velocities, two relatively simple alterations in Doppler signal processing are required: 1) the high pass filter is bypassed and 2) lower gain amplification is used to eliminate the weaker intensity blood flow signals [10].

TDI Modes

Color TDI

In conventional echocardiography Doppler signals from red blood cells are detected at each sampling site along the ultrasound beam. The frequency shift is measured and converted into a digital format. By autocorrelation method different velocities are correlated with a preset color scheme and, superimposed on the 2-dimensional image displayed as color flow on the monitor. Blood flow towards the transducer is color coded in red shades while blood flow away from the transducer is color coded in shades of blue. Velocities exceeding the Nyquist limit lead to aliasing and to reversal of color and variant colors respectively. In TDI, the same principles have been applied. The upper limit of measurable velocities is determined by the pulse repetition frequency, which is also the sampling frequency [11]. With the latest techniques, frame rates of up to 240/s can be obtained. Because ventricular wall motion velocity at rest is about 10 cm/s or less and increases up to 15 cm/s during stress aliasing is unlikely under these conditions. As for pulsed wave and continuous Doppler, Doppler shift and hence temporal and spatial resolution are dependent on frame rate which itself is correlated to probe frequency, pulse repetition frequency and sector angle [12].
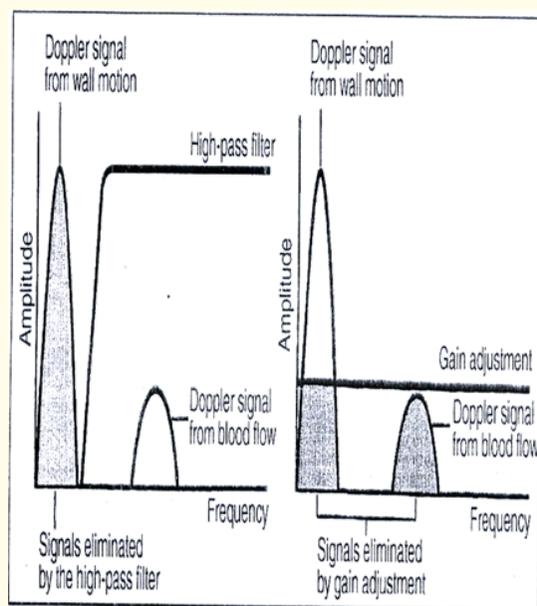
Figure 1: *In TDI, the same Doppler principles are used to quantify the higher-amplitude, lower-velocity signals of myocardial tissue motion.*

Clinical applications of color-coded TDI

No information regarding wall motion velocity can be obtained from the stop-frame images of conventional two-dimensional echocardiography. In contrast, color-coded TDI, in which wall motion velocity is superimposed on the two-dimensional echocardiography, permits visual assessment of wail motion velocity in real time. Therefore, it is possible to estimate the wall motion from both wall configuration and motion velocity [13]. With the present system, serial changes in the ventricular wall motion over time can be analyzed, particular with the use of M-mode color-coded tissue Doppler imaging. This ability may be applicable to detection of sites of early ventricular contraction associated with accessory pathways in patients with the Wolff-Parkinson-White syndrome [14].

Pulsed- Wave Tissue Doppler Imaging (PW-TDI)

This is the easiest way to measure myocardial velocities and has been used for interrogation of myocardial or mitral annular velocities. Using this modality a sample volume is placed in the ventricular myocardium immediately adjacent to the mitral annulus and a spectral display is obtained [15].

Technical issues associated with TDI: Certain pitfalls, which may affect or influence the Doppler signals:
1. Sample volume size and positioning
2. Doppler gain
3. Mitral annular calcification
4. Phase of respiration
5. Beam alignment

Gain: Gain can affect the peak Doppler tissue velocities. Therefore, gain should be minimized to allow for clear Doppler signals with minimal background noise [16].

TDI Annular Site: Although the E/E' ratio was the single best parameter for predicting mean left ventricular diastolic pressure (LVDP) for all levels of systolic function, Ommen., *et al.* [17] demonstrated that E/E' ratio using the medial annulus correlated better with mean LVDP. However, a recent publication showed that the lateral annular E' velocities used for the E/E' ratio correlated best with LAP when the EF is greater than 50%; if the EF was less than 50%, a combination of conventional and refined Doppler indices may be used without significant error [18].

Phase of Respiration: The phase of respiration affects TDI recordings in view of breathing-associated shifts in cardiac position. When possible, the sonographer should obtain lateral TDI during end expiratory apnea, to improve accuracy and consistency of the peak TDI velocities.

Sample Volume Size and Location: Placement at the annulus is critical to produce accurate Doppler tissue tracings. Subtle changes in sample volume positioning outside the annulus can highly influence the Doppler tracings [19]. The septal annulus has been reported to have less excursion, resulting in lower velocities than the lateral annulus [20]. Therefore, different sample volume size should be used for different annular location (lateral *vs* septal; septal annular imaging may improve with an approximate 3.5 mm sample volume, and lateral annular imaging improved with an approximate 5.0 mm sample volume). The rationale behind using different sample volume size is that increased lateral annular motion may require a larger sample volume to record the annular velocities properly. To optimize all components of the TDI signal, sample volume size should be proportional to annular motion and not limited to either septal or lateral annulus [21].

Mitral Annular Calcification: Mitral annular calcification (MAC) may influence annular motion by reducing its excursion. Soeki., *et al*. has shown that severe MAC is associated with elevated trans-mitral inflow velocities in the absence of significant valvular stenosis, and low E' velocities. Thus, for patients with extensive MAC, the E/E' ratio may be elevated. Whether elevation in this ratio reliably reflects elevated LAP has not been completely established by hemodynamic validation studies. Until further data is furnished on MAC and the estimation of early diastolic filling pressures, the sonographer should use caution when reporting the E/E' ratio [21].

Systematic approach for acquiring accurate TDI waveforms: [15]
The Sonographers Check list for more accurate and reproducible TDI
The following is a systematic approach that can guide the sonographer to obtain more accurate and reproducible annular Doppler tissue tracings:
1. Determine if the ultrasound manufacturer has preset Doppler tissue settings.
2. Optimize the apical 4-chamber view by aligning the cursor as parallel as possible through the annulus to avoid possible underestimation of the Doppler signal; an angle of insinuation less than 20 degrees parallel to annular plane will allow for more accurate Doppler velocities.
3. Sample volume size should be adjusted proportionally to annular motion: use a sample volume of approximately 3 mm for the septal annulus and 5 mm for lateral annulus. Carefully visualize the sample volume relative to annular motion and increase or decrease the sample volume size accordingly.
4. Once the Doppler cursor is aligned optimally, activate the Doppler tissue preset. Decrease the Doppler scale to less than 25 cm/s for better visualization of the peak annular velocities. A sweep speed between 50 and 100 mm/s is adequate for measurement of peak annular velocities.
5. Ask the patient to breathe in, breathe out, and then hold their breath at the end of expiration. Carefully reposition the sample volume directly into the selected portion of the annulus. Activate pulsed wave Doppler tissue. Peak TDI wave form velocities should be uniform, consistent, with little or no beat-to-beat variation of the peak velocities.
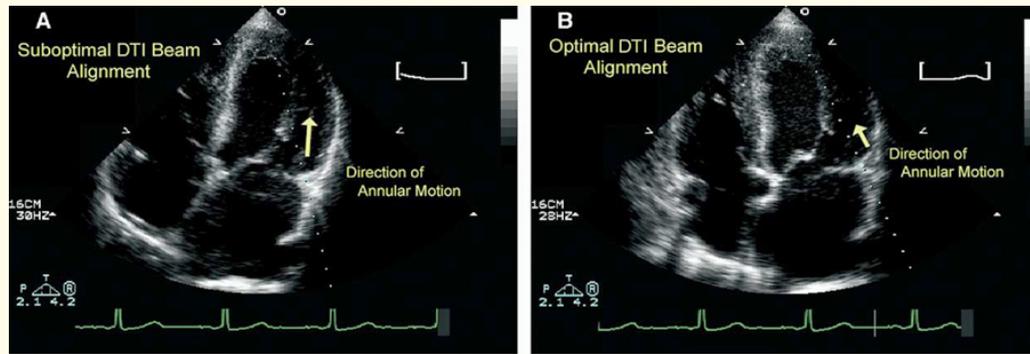
Figure 2: Suboptimal and optimal annular Doppler tissue imaging (TDI) beam alignment. A: Large angle of insonation (increased cosine) between Doppler beam and lateral annulus. As with other Doppler techniques, large insonation angle (cosine > 20 degrees) can lead to significant underestimation of annular velocities. B: in same patient, Doppler beam aligned more parallel (cosine < 20 degrees) to motion of mitral annulus. Alignment will result in more accurate recordings of annular velocities (21).

Reproducibility of TDI

To date, few studies have reported on the reproducibility of annular TDI. Vinereanu., *et al*. showed the best inter observer reproducibility of annular diastolic velocities when obtained from the lateral mitral annulus. Special attention to technical factors along with more accurate Doppler beam alignment perpendicular to the annulus may increase reproducibility [22].

Normal Pattern of Pulsed Wave TDI (Figure 3) [10]
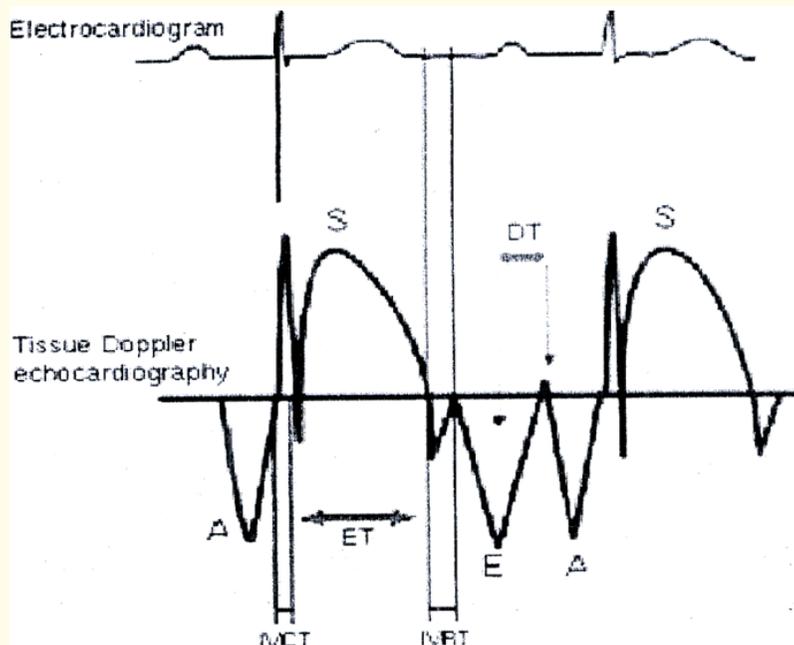
Figure 3: Tissue Doppler time intervals and velocities measured from lateral mitral annulus.
IVCT: Isovolemic contraction time; IVRT: Isovolemic relaxation time; S: The main systolic velocity; E: The early diastolic velocity; A: The late diastolic velocity; ET: Ejection time; DT: E-wave deceleration time (24).

From the velocity curve the following velocity waves can be identified:

Isovolumic Contraction Wave (IC-wave): This is biphasic wave (Ica & ICb) representing the isovolumic contraction phase (starts with Q-wave).

Systolic Wave: Large systolic wave occurs after (r-wave on ECG and extends to the end of the T-wave). Its peak velocity ranges from 8-18 cm/sec; it is usually positive wave except for the anterior wall and the septum in the parasternal views. The six-site average for peak systolic mitral annular velocity by pulsed wave TDI method of greater than 7.5 cm/sec is predictive of an ejection fraction greater than 50% with 88% sensitivity and 97% specificity [23].

Isovolumic Relaxation Wave: It starts from the end of the S-wave to the beginning of E-wave. The IVRT in healthy normal subjects ranges 35 ± 15msec to 76 ± 25 mesh with mean value of 52 ± 15 msec, there is some degree of heterogeneity being lower at the basal than at distal segments. This wave is biphasic wave IRa is the positive component. IRb is the negative component.

Early Filling Phase (ETDI): It coincides with the trans-mitral E-wave but peaks earlier than that of mitral flow. It ranges in normal subjects from 10 ± 3 cm/sec to 14.8 ± 3.9 cm/s. Also there is some heterogeneity of the peak ETDI from basal to mid and apical segments. It is usually negative wave except for the septum and anterior wall. The peak early diastolic velocity is blunted with restrictive cardiomyopathy and preserved constrictive pericarditis [23].

Late Filling Phase (ATDI): It follows the P-wave of ECG. Its normal values ranges from 5.8 ± 2.4 cm/s with some heterogeneity between different myocardial segments.

E' TDI/A' TDI ratio: It is the most sensitive important index of ventricular diastolic function. It ranges normally from 1.9 ± 0.9 to 3 ± 1.4 and correlates directly with the global E/A ratio: Alteration of left ventricular global diastolic filling depends on the magnitude and extension (number of segments) of regional diastolic dysfunction [1].

The biphasic signals during the isovolumic phases (contraction and relaxation) are low in velocity and of very short duration and they were considered due to muscular elasticity or translation of the heart during these phases of the cardiac cycle when pressure gradients act as constant left ventricular volumes. They are highly variable and therefore these waves are not included in the data analysis as the other three distinct deflections (S, E' and A' waves) [2].

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