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3D WALL MOTION TRACKING: IMPLEMENTING A NEW TOOL IN DAILY CLINICAL PRACTICE

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Abstract

Since the introduction of ultrasound in cardiology, the wish to quantify cardiac function was the driver for the development of new technologies. M-mode, which projects speckle information of cardiac structures over time, is so to speak the initial form of one-dimensional wall motion tracking. Two-dimensional speckle tracking is useful, has some limitations, though, because the heart has three dimensions. Now, the recently developed three-dimensional wall motion tracking (3D WMT) technology provides a new diagnostic tool. 3D WMT offers a new way to analyze the left ventricle and a new concept to assess its function. Moreover, it is not time-consuming and can thus be used as a routine analysis tool in daily clinical practice. 3D WMT is a new technique that can assess global and regional left ventricular function in a fast and comprehensive way. Its use may help the clinician to save time without having to make
compromises in terms of completeness and accuracy of the analysis.

Introduction

Traditionally, global left ventricular (LV) function has been evaluated using M-mode or two-dimensional (2D) echocardiography. More recently, three-dimensional (3D) echocardiography has been introduced in daily clinical practice. Segmental wall motion, however, has been difficult to assess. It is usually performed by measuring endocardium thickening, but this approach is limited by huge intraobserver and interobserver variability. Strain and strain-rate imaging have emerged as a quantitative technique to solve this problem (1). Both measurements have been obtained from tissue Doppler imaging (TDI), but TDI-based strain and strain rate have several limitations: angle-dependent measurements (due to the use of Doppler) and simultaneous opposite deformation

in the long and short axes (2). A new technique called wall motion tracking (WMT) seems to solve the problem associated with TDI. The recent development of three-dimensional wall motion tracking (3D WMT) technology provides a new diagnostic tool: it is a fast new way to analyze the left ventricle and a new concept to assess left ventricular function.

Wall Motion Tracking

Speckle in ultrasound images is a phenomenon caused by interference of waves from randomly distributed scatterers in the myocardium. These scatterers are too small to be detected by ultrasound technology. Speckle degrades both spatial and contrast resolution by creating fine false structures, the so-called speckle noise. This phenomenon has a very important characteristic: speckle moves with the tissue. Thus, the speckle pattern follows the myocardial motion. Furthermore,
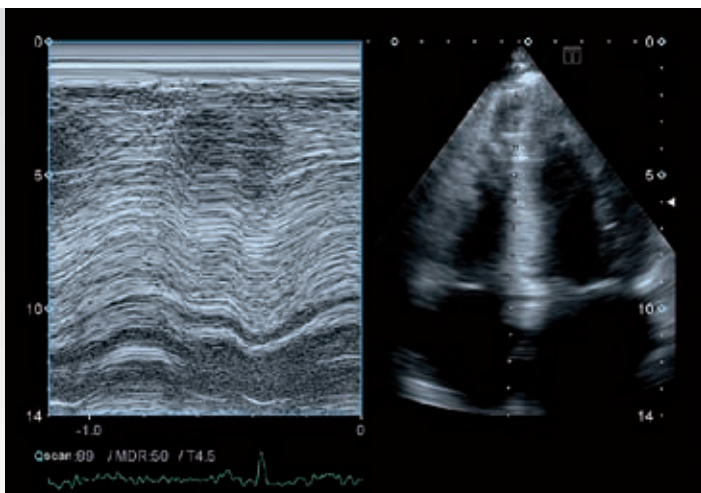

Fig. 1: Left ventricular septum M-mode shows how speckle moves with tissue.
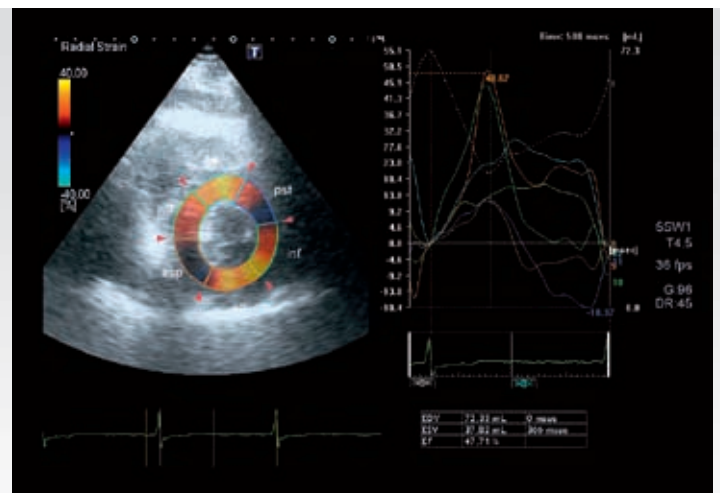

Fig. 2: Left ventricular 2D WMT evaluation. The analysis of a short axis view is shown. The analysis of the whole left ventricle is very time-consuming.

each region of the myocardium shows a different speckle pattern due to the characteristic randomness of this phenomenon. Thus, a unique pattern is created for any selected region that can identify this region and the displacement of the region in the next frame. Motion is analyzed by integrating frame-to-frame changes (3). Velocities can be calculated by the geometric shift of each speckle. The basic parameter of this information is displacement, and based on this value other parameters can be obtained (4, 5, 6). Because M-mode projected the speckle information of the cardiac structures over time, it was so to speak the first form of one-dimensional speckle tracking (Fig. 1). One of the most important advantages of this method studied by Sivesgaard et al is the fact that there is no angle-dependency and multiple parameters can be calculated in different views. (7)

2D Wall Motion Tracking

Two-dimensional wall motion tracking (2D WMT) consists of a template image created using a local myocardial region in the starting frame of the image data. In the next frame an algorithm searches for the local speckle pattern that most closely matches the template. A movement vector is created using the location of the template and the matching pattern in the subsequent frame. Multiple templates are used to observe movement of the entire myocardium. The process is repeated by creating new templates and observing their movement in the subsequent frames until the entire cardiac cycle has been assessed.

Classically, strain and strain rate have been parameters obtained from tissue Doppler data (1). Nevertheless, WMT technology allows a new and more direct approach to obtain these parameters. 2D WMT can quantify regional myocardial deformation independently of insonation angle (7) and thus simultaneously assess long and short axis deformation. In this way, circumferential, radial and longitudinal strain can be obtained (2, 8, 9). Furthermore, other parameters such as rotation, shear, twist and torsion may be evaluated (Fig. 2). WMT-derived strain and strain rate provide clinical relevant information in a huge number of cardiac diseases. Ingul et al analyzed patients with myocardial infarction and showed no difference between TDI and 2D WMT parameters in the infarcted area. Their results, however, showed that automated analysis methods were faster than and as accurate as manual analysis (10). Seo et al studied thirty-three patients with severe symptomatic heart failure despite optimal pharmacologic therapy and showed that assessing left ventricle dyssynchrony using speckle tracking echocardiography results in a high rate of success for dyssynchrony assessment and clinically acceptable reproducibility (11). Similar results were obtained by Delgado et al (12).

3D Wall Motion Tracking

The heart has three dimensions. Cardiac motion is 3D and speckle noise moves in the three spatial directions. Thus, 2D WMT is limited because it cannot assess movement in the third dimension. The main difference between 2D and 3D WMT is that, although both techniques use ultrasound image data to detect movement of the myocardium, 2D WMT employs 2D movement or the projection of 3D movement into a 2D plane, whereas 3D tracking assesses real movement in 3D, not just a projection. 2D data is not used in this technique at any point. 3D WMT was developed as a new
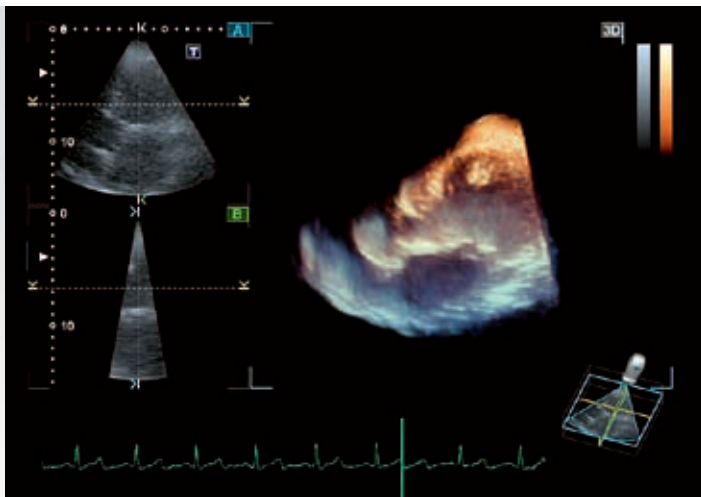

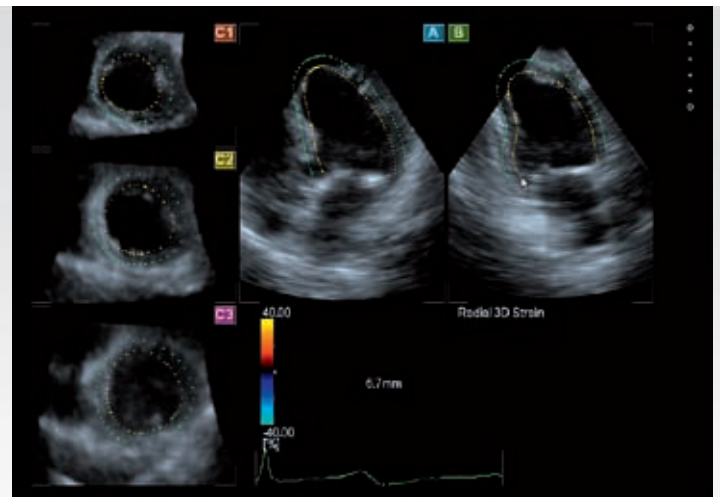Fig. 3: 3D WMT detects speckle motion in three dimensions.

Fig. 4: Left ventricular semi-automatic tracking. The user sets three markers in planes A and B. The software detects the LV endocardium and the epicardium. See text for details.

application that can be used for regional wall motion analysis of the entire LV and allows to obtain real 3D indices and to assess 3D wall motion precisely with an improved integration of heart structures (Fig. 3). It is capable of displaying results for the entire myocardium using a single dataset to assess truly global LV. An overall dataset enables the user to observe new indices (e.g. torsion), true 3D strain and a host of other previously unobserved parameters (13).

3D speckle tracking has several advantages: all vectors of tissue tracking are tracked within the full volume. Moreover, lower volume rates can be used and it provides a better vector calculation which is more adequate for clinical scanning conditions and there is no loss of the speckle particle in 3D.

3D WMT requires the new Artida system and the PST-25SX 1 MHz to 4 MHz phased-array matrix transducer, both by Toshiba Medical Systems Corporation, Otawara, Japan. These two devices optimize 3D image acquisition. The matrix transducer can scan a user-selected volume that can

be adjusted from 15º x 15º to 90º x 90º. For real-time purposes, one-beat acquisition is used and a triggered acquisition mode is available for advanced analyses. In the triggered mode (the mode used for 3D WMT evaluation), a live monitoring mode allows the user to monitor the reconstruction of the full-volume data set. The standard application setting is the use of four subvolumes of 90º x 22.5º, which results in a 90º x 90º triggered full volume in four heart cycles. During the acquisition, a five-plane view of the four- and two-chamber apical views and short axis planes at apex, mid and base of the LV is guiding the user to keep the best transducer position and updates the acquisition process continuously. During acquisition it is of great importance for the subvolume to match well which can be monitored on the screen. If a mismatch appears, the examiner can continue the acquisition process until the mismatch disappears in the following heart cycles shown on the monitor. A retrospective acquisition method is used and after 'freeze' the best full-volume datasets can be selected from the image memory. A template for the B and C planes is available to set the right orientation of the A, B

and C planes in order to achieve optimum plane selection.

Each 3D data set is displayed in a five-plane view: (A) an apical four-chamber view; (B) a second apical view orthogonal to plane A; and (C) three short-axis planes: plane C1 in the apical region, plane C2 in the mid-ventricle and plane C3 at the basal portion of the left ventricle. The user then sets three markers on planes A and B; in each plane, one marker is set at the apex and the other two at the edges of the mitral valve ring. The software then detects the LV endocardium, and the user sets a default thickness for the myocardium (Fig. 4). The software splits the LV into 16 segments automatically according to the American Heart Association standards for myocardial segmentation. After the markers have been selected, the system performs the 3D WMT analysis through the entire cardiac cycle. The selection of the LV shape is semiautomatic and the tracking process is automated, but the user can adjust the results of the tracking process if needed. Finally, the results of the 3D WMT analysis are presented as averaged values for each segment.
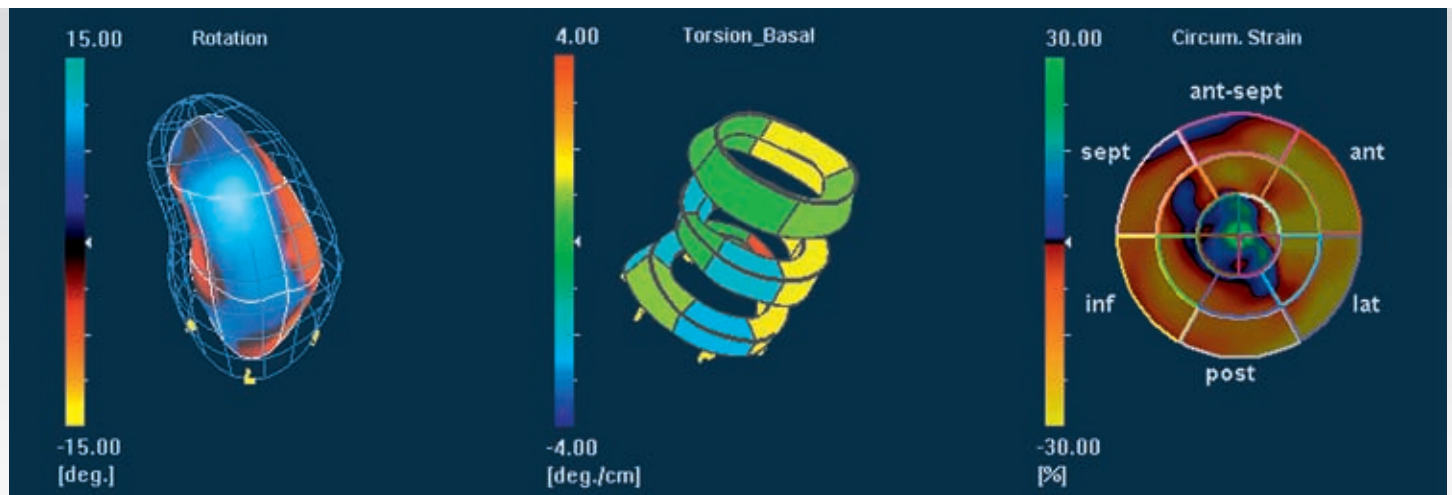

Fig. 5a: A patient with hypertrophic cardiomyopathy. The type of display selected to present the results of the analysis of the left ventricular rotation is the so-called "plastic bag".

Fig. 5b: In this case, the selected parameter is the left ventricular torsion and the type of display chosen is the "doughnut view".

Fig. 5c: Polar map. Another way to present the 3D WMT results graphically.

The 3D WMT analysis results can be displayed in different ways, such as the "plastic bag" (Fig. 5a), the "doughnuts view" (Fig. 5b) or the "dynamic polar map" (Fig. 5c) among others. The user can select from a wide variety of displays the one that shows the results most clearly. All these data may also be obtained in numeric format.

The new 3D WMT system works well with medium-quality echocardiography images. Saiko et al enrolled fifty-six healthy volunteers; ten subjects were excluded because of poor image quality (15). In a study by our group thirty patients were analyzed and only two were excluded because of poor acoustic windows (14). Furthermore, our results show how the 3D probe can obtain a more complete analysis, because the entire left ventricle may be analyzed from only one apical position and the sonographer does not need to change to different positions to obtain different planes. The 3D WMT technique is a simple, feasible and reproducible method to measure longitudinal, circumferential and radial strain values (15).

Time-saving is one of the main advantages of 3D WMT because all segments are calculated in one analysis step. Within 20 seconds, the result of 3D WMT is available with a large variety of parameters to read myocardial function. Different parameters such as displacement and strain in longitudinal, radial and circumferential orientation are available in addition to the 3D vector-based variants. Moreover, new parameters such as twist and torsion are selectable based on rotation information which is also available as a display parameter.

Saiko et al and our group showed that interobserver and intraobserver agreement for radial and longitudinal strain measurements on 3D WMT were good (14, 15).

The 3D WMT analysis not only provides information regarding the segment analysis of the left ventricular myocardium, it also provides a robust evaluation of LV volume during the heart cycle. The detection of the endocardium for wall motion purpose is also useful to obtain the inner dimensions of the LV 3D shape and the myocardial volume. Thus, the system also provides information regarding LV volumes and LV ejection fraction and the related volume curves are presented time-aligned with the segmental parametric imaging curves. The detection of the endocardium is based on 3D tracking information and not on 2D plane assumptions. The 3D shapes can be corrected by the user when needed in five orthogonal planes. Thus, the assessment of the LV volume is anatomical correct and robust. It results in a reproducible calculation of LV volumes and ejection fraction (Fig. 6).

3D WMT is a new tool which has demonstrated its usefulness in several clinical scenarios. It has a promising role in the evaluation of different heart diseases such as dilated cardiomyopathy, left ventricular asynchrony evaluation and ischemic heart disease (10).

3D WMT has a material limitation in time and spatial resolution. However, there was no sig nificant difference in the time to peak strain between 3D WMT and 2D WMT. In addition, equivalent reproducibility of 3D WMT was demonstrated compared with 2D WMT (15).
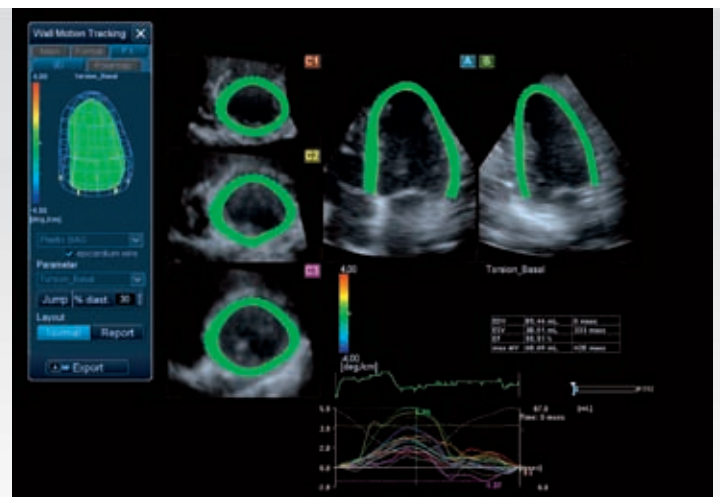

Fig. 6: Automatic calculation of left ventricular volumes and ejection fraction based on 3D WMT technology below the LV four-chamber view. The system automatically displays this information together with the wall analysis.

3D WMT: Exploring new parameters

Area tracking is a new parameter of regional and global LV function provided by 3D WMT on the Artida premium class ultrasound system from Toshiba Medical Systems. Area tracking reflects the 3D radial strain and is based on endocardial changes only, which makes the method very sensitive for detecting ischemic reactions in the myocardium which are most easily to recognize in the sub-endocardial layers (Fig. 7). This new method reflects the deformation of the endocardial surface during LV contraction and relaxation. The application in combination with stress echo is a very promising tool to quantify stress echo readings. Area tracking facilitates detection of dyssynchrony and can be used in the selection of patients for cardiac resynchronization therapy (Fig. 8).

Conclusions

3D WMT is a new technique to assess global and regional left ventricular function quickly and comprehensively. It can help the clinician to save time without having to make compromises in terms of completeness and accuracy of the analysis.

3D WMT is a potential clinical bedside tool for quantifying global and regional left ventricular function.

New parameters such as area tracking with regard to screening and follow-up of patients with ischemic heart disease or dyssynchronous wall motion are being evaluated.
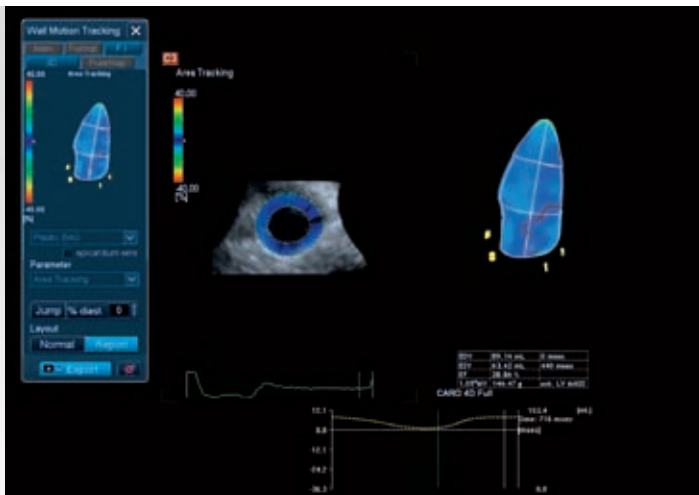

Fig. 7: Area tracking. A patient with ischemic cardiomyopathy and severely depressed left ventricular ejection fraction.
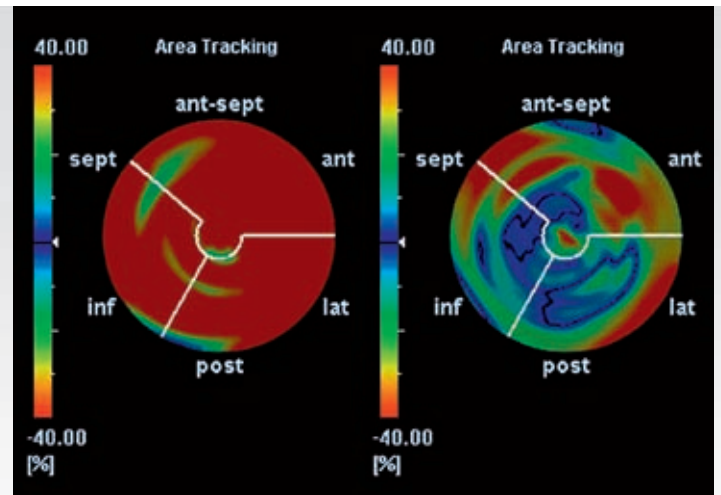

Fig. 8: On the left-hand side, area tracking of a patient without heart disease is shown and on the right-hand side, area tracking of a patient with severe ischemic heart disease is shown. The akinetic area is represented in blue.

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Abbreviations

2D	= two-dimensional
WMT	= wall motion tracking
2D WMT	= 2D wall motion tracking
3D	= three-dimensional
3D WMT	= 3D wall motion tracking
LV	= left ventricle
TDI	= tissue doppler imaging

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