Willem Gorissen
Toshiba Medical Systems Europe
Zoetermeer, Netherland
Introduction
Since the introduction of ultrasound in cardiology, the desire to quantify cardiac function has been driving the development of new technologies. After simple initial diameter measurements using amplitude of reflections (A-mode), M-mode followed, providing the ability to assess valve and wall motion over time. Since M-mode projects the speckle information of the cardiac structures over time, it is – so to speak – one-dimensional speckle tracking.

This relatively simple method allowed more detailed insights in wall motion in various cardiac conditions. In the early 1980s, 2D echocardiography boosted the use of ultrasound in medicine. In the mid-90s, Toshiba Medical Systems introduced tissue Doppler imaging (TDI) which accelerated the search for more detailed analyses of wall motion and increased the knowledge of heart function. The use of two-dimensional information to quantify wall motion was developed, but the required computing power has only recently become available. With the Artida system, Toshiba created a platform for a new clinical tool to assess global and regional cardiac function using two-dimensional as well as three-dimensional speckle tracking technology: wall motion tracking (WMT). Tissue Doppler-based calculations of myocardial strain are possible for structures which move in the same direction as the ultrasound beam, but they are incorrect if the beam moves in other directions and even impossible with angulations close to 90°. Consequently, several segments of the LV cannot be studied with the use of TDI-based strain calculations. 2D WMT overcomes this limitation!

Technology
The basis of WMT is the tracking of ‘speckles’ in a 2D plane or in a 3D volume. Speckles are disturbances of ultrasound by reflectors in the ultrasound beam. Each structure in the body has a specific speckle pattern which can be recognized in an image using pattern matching technology.

Fig. 1: The actual thickening of the LV, which was measured routinely in the late 1970s and early 1980s by M-mode, was called ‘strain’ in the late 90s when tissue Doppler-based wall motion parameters were explored.

Fig. 2: Speckles are identified in each volume by pattern recognition. In the consecutive volume the new position of each speckle is determined by regional pattern matching technology. Amplitude and direction of movement in 3D space provide quantitative information about myocardial wall motion.
A sample of a group of speckles is used to identify the position changes in consecutive images. Thus, the distance or ‘displacement’ of the structure can be calculated. By using hundreds of these samples in a single image, it is possible to provide regional information of the displacement of the LV walls. Based on this displacement information, other valuable parameters can be derived such as velocity, strain rate and strain. Strain reflects the deformation of LV wall segments. This method allows the calculation of thickening, thinning, shortening, lengthening and rotation of a segment. A strong advantage of 2D and 3D WMT is angle independency (Fig. 2).

2D WMT

Applied to standard two-dimensional images acquired during routine ultrasound exams, 2D WMT provides robust information of the segmental changes in the LV. 2D WMT offers the advantage of good temporal resolution since the real-time 2D information is captured at frame rates between 50 and 150 fr/s depending on scan range width and depth. Using parasternal short axis views the radial parameters can be detected in each segment based on an average of hundreds of data points in each segment (Fig. 3).

3D Acquisition

3D technologies are used to create a full volume data-set of the left ventricle. In order to calculate wall motion in three dimensions, a well-balanced dataset in terms of spatial and temporal resolution is required.

Although a single full volume acquisition of the complete heart is possible during one cardiac cycle, in clinical practice the acquisition of four sub-volumes, each covering a complete cardiac cycle, is preferred. In a second step, advanced digital processing technique are used to stitch the four sub-volumes together to form a complete volume dataset (Fig. 4). During the acquisition, a five-plane view of the four and two chamber apical views and short axis or (C-) planes at apex, mid and base of the LV guides the user to the best transducer position and continuously updates the acquisition data. During acquisition it is crucial to match the sub-volumes which can be monitored on the screen. If mismatches occur, the examiner can continue the acquisition process until the mismatch disappears in later heart cycles which are shown on the monitor.

Retrospective acquisition facilitates the entire process 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 orientate these planes in order to achieve the best possible plane selection. This convenient approach renders the application particularly helpful for routine use (Fig. 5).

3D WMT

In 2D WMT the information is based on the assumption that the structures move in a 2D plane, while in reality the structures of course move in three dimensions. In order to overcome this disadvantage and investigate LV function in all three dimensions, 3D WMT has been developed. Here, myocard motion is detected in all three dimensions and the real motion vector is provided. These data
allow assessment of the LV function. The structures of the LV are captured in a full volume and do not move ‘out of plane’ like in 2D. Moreover, relations between segments such as twist and torsion of the LV are provided.

3D WMT uses a box template to detect speckle motion in three dimensions. Parametric imaging projects the parameter value on the endocardial layer. 3D volumes are calculated simultaneously (Fig. 6).

A 3D shape based on 3D WMT results can be displayed while the parametric information, e.g. strain, is projected on the endocardial surface. Since the volume rate can be set around 20 to 30 volumes per second, peak strain and displacement information can be detected for clinical use. An advantage of this volume rate is the fact that the detected vector is longer than in high frame rates and therefore can be more accurate (Fig. 7).

**Workflow**

After acquisition of a 3D full volume dataset, the 3D WMT analysis can be performed. To apply 3D WMT to a dataset, the user has to provide some reference points. In the selected A plane, which is typically the apical four-chamber view, the user has to fix three reference points for WMT, two at the base of the LV at the mitral valve level and one at the apex. The same three points are used for the B plane, which is the 90° orthogonal plane to the apical four-chamber view. With these six reference points, the system will automatically detect the endocardial border. The epicardial border can be entered manually or by setting a default ‘thickness’ for the myocardium. After detection of the myocardium borders at the end-diastolic reference frame, if needed, the user can correct the shape of the LV reference at the starting image. When the user has accepted the shape of the LV at end diastole, the 3D wall motion tracking process can be started. Within 20 seconds, the results of 3D WMT are available, offering many parameters to interpret myocardial function.

Because the complete analysis takes only a few minutes, the method can be performed on the spot either directly on the ultrasound system or off-line on a dedicated workstation. The acquired data are stored in raw data format which allows off-line analysis with the same accuracy as the online procedure. Future parametric techniques can be retrospectively applied to stored datasets.

**Segmentation**

For optimal integration of the methods in the clinical routine, standard segmentation is applied using the 16-segment model as suggested by the American Society of Echocardiography (ASE) or the 17-segment model proposed by the American Heart Association (AHA) (Fig. 10).

**LV Volume and Ejection Fraction**

3D WMT opens the door to more robust evaluation of cardiac volume during the heart cycle. Parallel to the detection of the endocardium for wall motion purposes, WMT presents the detected volume information in line with the other parameters from the same tracking data. The inner dimensions of the 3D shape and the myocardial volume are presented as basal information and the related parameters can be used for accurate evaluation.

---

Fig. 5: Retrospective acquisition facilitates the entire process and after ‘freeze’ the best full-volume datasets can be selected from the image memory.

Fig. 6: 3D WMT uses a box template to detect speckle motion in three dimensions. Parametric imaging projects the parameter value on the endocardial layer. 3D volumes are calculated simultaneously.

Fig. 7: Parametric imaging in three dimensions. On the left peak circumferential strain at end systole, on the right torsion showing strong outward vectors at early diastole.
volume curves are displayed time-aligned with the segmental parametric imaging curves.

Detection of the endocardium is based on 3D tracking information and not on 2D plane assumptions. If required, the 3D shapes can be corrected by the user in five orthogonal planes. Thus, the calculations are anatomically correct and very robust, resulting in reproducible calculations of LV volumes and ejection fraction (Fig. 11).

Coronary Artery Disease
One of the most important clinical applications will be the assessment of wall motion in coronary artery disease. Detailed regional wall motion based on the 16-segment ASE or 17-segment AHA models is provided. All previously mentioned parameters can be generated in their 3D anatomical relation on the LV-shaped parametric display as well as Time Curve (TCA) demonstrating the segmental and global parameter change during the cardiac cycle. Thus, temporal changes and timing of all parameters can be visualized and measured. These time curve images can be stored in the patient’s Dicom database and exported to Ascii-based text files containing all parametric numerical data per segment for user-specific and statistical calculations.

In addition to the 3D values, the user can select the radial, longitudinal as well as circumferential vectors of strain and displacement (Fig. 12–13).

Stress Echo
Today, stress echo is a proven clinical tools. The interpretation of segmental wall motion, however, requires experience and expertise and is to a certain degree always subjective. Since WMT provides an objective method to detect and quantify wall motion, the application potentially improves reproducibility when used in combination with stress echo. 2D data captured during a routine stress echo and stored can be used for 2D WMT. A raw data set could be used as well. The standard stress protocol can be ‘paused’ for additional data acquisition in each phase for example for 3D. Advanced methods for more detailed and quantifiable wall motion parameters are within reach. Here, 3D WMT adds an interesting value to the ‘eye-balling’ qualitative analysis which has been applied until now.

Heart Failure and CRT
Not only the assessment of the strain values but also the timing of events is of clinical importance. Delayed contraction in ischemic heart disease and heart failure can be visualized which leads to possible applications of 3D WMT in the screening selection and follow-up of patients who are candidates for cardiac resynchronization therapy (CRT). Fast acquisition and comprehensive information of all segments of the LV facilitates the use of this practical method also when optimizing CRT devices right after implementation (Fig. 14).
Conclusion

The introduction of the Artida heralded the beginning of a new era in cardiac ultrasound. State-of-the-art ultrasound-based assessment of cardiac function using full three-dimensional information is now available and can be performed during the examination! Although further evaluation is required, 3D WMT provides clinicians with a more robust method to gain global and regional cardiac function information in every day practice, including new and exiting parameters such as twist and torsion.

Fig. 12: 3D displacement in normal heart on the left and apical infarction on the right. Note the blue area indicating low displacement values at the apex apical-lateral wall.

Fig. 13: Polar map of radial strain at end systole in a normal volunteer at the left and a patient with an apical infarction on the right. Note the lower strain values indicated by the dark red colors and blue areas indicating dyskinetic wall motion. Note the hyperkinetic motion of the basal lateral wall indicated by the bright yellow color.

Fig. 14: 2D WMT (left) demonstrates delayed contraction of the lateral wall (blue curve) and 3D WMT with dyssynchrony imaging (right). The red colors indicate areas with delayed contraction in LBBB.