Three-dimensional Wall Motion Tracking:
A Novel Echocardiographic Method for the Assessment of Ventricular Volumes, Strain and Dyssynchrony

Jeffrey C. Hill, BS, RDCS, FASE
Echocardiography Laboratory, Cardiac Resynchronization Therapy Clinic
University of Massachusetts Memorial Healthcare, Worcester, Massachusetts

Jennifer L. Kane, RCS
Echocardiography Laboratory, Cardiac Resynchronization Therapy Clinic
University of Massachusetts Memorial Healthcare, Worcester, Massachusetts

Gerard P. Aurigemma, MD, FASE
Echocardiography Laboratory, Cardiac Resynchronization Therapy Clinic
University of Massachusetts Memorial Healthcare, Worcester, Massachusetts

William M. Kenny, RDCS
Toshiba America Medical Systems, Inc.
Tustin, California

Berkley L. Cameron, MBA, RDCS
Toshiba America Medical Systems, Inc.
Tustin, California

REFERENCES:

www.medical.toshiba.com
Echocardiography plays an important role for the assessment of ventricular function in patients with heart failure symptoms. Recent advancements in echocardiography permit measurement of myocardial mechanics through the use of strain imaging. Current techniques are either Doppler based or rely on speckle tracking in two dimensions, but each has limitations. Accordingly, three-dimensional wall motion tracking (3D-WMT) offers rapid acquisition of ventricular volumes and strains, and can potentially overcome the limitations of tissue Doppler based or two-dimensional techniques.

It is well known that congestive heart failure (CHF) is common, with an estimated 500,000 new diagnoses per year in the US, and is associated with significant morbidity and mortality. Heart failure is primarily a disease of the elderly; approximately 6% to 10% of people older than 65 years have CHF, and approximately 80% of patients hospitalized with CHF are more than 65 years old. Clinical symptoms in patients with heart failure include dyspnea, fatigue and edema and are associated with lower quality of life (QoL) scores.

It has been observed that patients with CHF due to left ventricular (LV) systolic dysfunction have a high prevalence of intraventricular conduction abnormalities, i.e., left bundle branch block or non-specific intraventricular delay, seen on 12-lead electrocardiography (ECG). Among these patients, the prevalence of intraventricular conduction abnormalities increases significantly as LV ejection fraction (EF) declines and ECG-QRS duration increases (>120 msec). Intraventricular conduction abnormality can lead to dyssynchronous electrical activation and abnormal contraction of the various LV wall segments. Abnormal electromechanical function may contribute to atrio-ventricular dysynchrony, increased mitral regurgitation and LV volumes and reduced EF (Figure 1).

Recent investigations involving selected patients with systolic heart failure and prolonged QRS duration have shown efforts to better synchronize ventricular contraction with the use of a biventricular pacemaker or cardiac resynchronization therapy (CRT). Such biventricular pacing has been associated with improvements in heart failure symptoms, exercise capacity, QoL, and hospitalization rates for heart failure compared to standard medical therapy. However, in clinical trials, approximately 30% of heart failure patients selected for CRT on the basis of a prolonged QRS duration (>120 msec), do not demonstrate improvement in status, leading to the desire to refine selection criteria for this invasive and expensive technology.

Echocardiographic determination of ventricular volumes and dysynchrony in selected patients may predict better CRT outcomes compared to standard criteria. The most common echocardiographic techniques used for measurement of ventricular dysynchrony include traditional color tissue Doppler imaging (TDI) and newly developed, two-dimensional (2D) “speckle” strain imaging (SI). Color TDI is a Doppler method and is therefore limited by insonation angle dependency, allowing evaluation of strains primarily from the longitudinal axis (apical views); SI, although considered angle independent, is limited by insonation angle dependency and the assumption that ultrasound speckles can be tracked from frame to frame, despite “out of plane” motion. 3D-WMT, a next-generation strain and volumetric analysis, has recently been validated with cardiac MRI (Figure 2) and demonstrates better correlation of ventricular volumes compared to SI. The application of 3D-WMT has been reported to have faster acquisition and analysis time for the assessment of strain, function and outcomes compared to standard criteria. The polar-mapping application can be extended to Dyssynchrony Imaging or DI. This technique permits rapid evaluation of LV mechanical delay with the use of displacement imaging based on a parametric timing sequence. Unlike strain, which calculates the percent thickening or shortening of a specific region, displacement imaging calculates the time (milliseconds) and distance (millimeters) each myocardial segment is traveling throughout the cardiac cycle. Because displacement is not corrected for the absolute length of the contracting segment from which it was measured, a gradient from the base of the heart to apex is seen (i.e., highest displacement occurring at the base, lowest displacement occurring at the apex). In a patient with normal LV function and contraction sequence, segments within the polar map are color-coded green throughout the cardiac cycle.
Figure 1: These images were taken from the study of a patient with CHF and severe mitral regurgitation in the apical four chamber view (A); severely reduced LV function (EF = 17.8%) with significantly increased end-diastolic (296.4 ml) and end-systolic (243.4 ml) volumes (B); atrioventricular dysfunction of the mitral inflow (C); and significant ventricular longitudinal dyssynchrony. The septal to lateral wall delay was 260 ms (D).

Figure 2: Above, linear regression correlation between 3D speckle tracking end-systolic volumes (A), end-diastolic volumes (B) and CMR. Below, Bland-Altman agreement between 3D speckle tracking end-systolic volumes (C), end-diastolic volumes (D) and CMR. Note the excellent correlation and agreement between the two methods: STE, speckle tracking echocardiography of ESV, end-systolic volumes, and EDV, end-diastolic volumes compared with CMR, cardiac magnetic resonance imaging.

Figure 3: Normal patterns of 3D-WMT strains. 3D image cast representing the three vectors of myocardial deformation: longitudinal (long axis), circumferential and radial (short axis) (A), longitudinal strains (B), circumferential strains (C), radial strains (D). Both longitudinal and circumferential (shortening) waveforms are negative and displayed below the baseline; radial (thickening) waveforms are positive and displayed above the baseline. Note also that ventricular volumes and EF are reported from the 3D data set (panel B) permitting complete assessment of size and function.

Figure 4: 3D-WMT radial strain imaging in a normal patient (A). The polar-mapping has a homogeneous display indicating myocardial systolic thickening (radial strain) is normal, occurring at or near end-systole (the end of the T wave on ECG). To the right are the corresponding radial strain waveforms with the alignment of the peaks occurring at or near end-systole. 3D-WMT radial strain imaging in an abnormal patient with LV dysfunction and dyssynchrony (B). Myocardial thickening is non-uniform with heterogeneity within the polar map. Peak strains occur both early and late throughout the cardiac cycle. This pattern of dyssynchrony is typical in a patient with LV dysfunction and wide QRS complex.
indicating no significant delay in time to peak longitudinal displacement, up to 50 ms after aortic valve closure, between each segment (Figure 5a). Color-coding of yellow, orange or red within a segment during the diastolic phase of the cardiac cycle is suggestive of mild, moderate or severe delay. In Figure 5b there is significant heterogeneity (yellow and red) within the polar map, with red at the apex occurring in early diastole, rapidly identifying delayed segments and dysynchrony.

PATIENT HISTORY
A 40-year-old male with a history of nonischemic cardiomyopathy was referred to the Cardiac Resynchronization Therapy Clinic for clinical evaluation and implantable cardiac defibrillator (ICD) upgrade. History included alcohol and drug abuse, atrial fibrillation and ventricular tachycardia. Because of ventricular arrhythmias, an ICD was implanted. Physical exam demonstrated dyspnea, NYHA class IV heart failure with an EKG QRS duration = 158 ms.

PRE-IMPLANT ECHOCARDIOGRAPHIC EVALUATION
The echocardiogram showed a severely dilated LV with severe global hypokinesis. The 3D EF was 17.6 % and the LV end-systolic and end-diastolic volumes were severely increased (ESV = 550.8 ml, EDV = 668.5 ml). There was moderate to severe mitral regurgitation with a restrictive filling pattern, consistent with low-normal right ventricular systolic function. There was mild tricuspid regurgitation and severe pulmonary hypertension with a PASP of 66 mmHg.

3D STRAIN IMAGING
Three-dimensional radial strain imaging showed significant heterogeneity throughout the polar map (Figure 5a). Although dysynchronous, the majority of the strain waveforms are positive (thickening) and displayed above the baseline. There was significant reduction in peak radial strains with the latest site activation occurring in the inferior, septal and apical walls (arrow).

3D SYNSYCHRONY IMAGING
Dysynchrony Imaging showed severe delay (red) occurring in the septal and inferior segments (Figure 7a). The corresponding displacement waveforms showed severe post systolic displacement occurring well beyond mechanical systole, i.e., after aortic valve closures, (arrow). Although dysynchronous, the majority of the displacement waveforms are displayed above the baseline and the segments are moving in the same direction.

Based on clinical and echocardiographic criteria (QRS duration ≥ 120 msec, EF ≤ 35%, drug refractory CHF), a decision was made to upgrade his ICD to a biventricular pacemaker was made.

ONE MONTH FOLLOW-UP
Device interrogation showed an episode of nonsustained ventricular tachycardia. Following CRT, in panel B the EF decreased from 17.6 % to 12.8 %, end-systolic volumes increased from 550 ml to 589 ml. The strain waveforms are bi-directional with increased “thinning” consistent with worsening dysynchrony (arrow). The pattern of dysynchrony in contrast to what was shown in figure 4B is less common.
Three-dimensional Wall Motion Tracking: A Novel Echocardiographic Method for the Assessment of Ventricular Volumes, Strain and Dyssynchrony

Jeffrey C. Hill, BS, RDCS, FASE
Echocardiography Laboratory, Cardiac Resynchronization Therapy Clinic
University of Massachusetts Memorial Healthcare, Worcester, Massachusetts
Jennifer L. Kane, RCS
Echocardiography Laboratory, Cardiac Resynchronization Therapy Clinic
University of Massachusetts Memorial Healthcare, Worcester, Massachusetts
Gerard P. Aurigemma, MD, FASE
Echocardiography Laboratory, Cardiac Resynchronization Therapy Clinic
University of Massachusetts Memorial Healthcare, Worcester, Massachusetts
William M. Kenny, RDCS
Toshiba America Medical Systems, Inc.
Tustin, California
Berkley L. Cameron, MBA, RDCS
Toshiba America Medical Systems, Inc.
Tustin, California

REFERENCES:

Three-dimensional Wall Motion Tracking: A Novel Echocardiographic Method for the Assessment of Ventricular Volumes, Strain and Dyssynchrony

Jeffrey C. Hill, BS, RDCS, FASE
Echocardiography Laboratory, Cardiac Resynchronization Therapy Clinic
University of Massachusetts Memorial Healthcare, Worcester, Massachusetts
Jennifer L. Kane, RCS
Echocardiography Laboratory, Cardiac Resynchronization Therapy Clinic
University of Massachusetts Memorial Healthcare, Worcester, Massachusetts
Gerard P. Aurigemma, MD, FASE
Echocardiography Laboratory, Cardiac Resynchronization Therapy Clinic
University of Massachusetts Memorial Healthcare, Worcester, Massachusetts
William M. Kenny, RDCS
Toshiba America Medical Systems, Inc.
Tustin, California
Berkley L. Cameron, MBA, RDCS
Toshiba America Medical Systems, Inc.
Tustin, California

REFERENCES: