Apex to Base Left Ventricular Twist Mechanics Computed from High Frame Rate Two-Dimensional and Three-Dimensional Echocardiography: A Comparison Study

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Background: The aim of this study was to compare two-dimensional (2D) and three-dimensional (3D) methods for computing left ventricular (LV) rotation.

Methods: A two-axis linear/rotary system was designed using rotary motors controlled through a digital interface, and 10 freshly harvested pig hearts were studied. Each heart was mounted on the rotary actuator with the base being rotated at different known degrees of rotation (10°, 15°, 20°, and 25°) and was passively driven by a pump with calibrated stoke volume (50 mL) at a constant rate (60 beats/min) simultaneously. Cardiac motion was scanned to acquire 2D short-axis views using a GE Vivid 7 system for assessing rotation, and 3D apical full-volume loops were acquired using a Toshiba Applio Artida ultrasound system. Full-volume 3D image loops were analyzed online with Toshiba Wall Motion Tracking software, and short-axis 2D images were analyzed offline for LV rotation in GE EchoPAC PC at corresponding LV levels.

Results: At each state, both 2D and 3D echocardiography detected the changes in LV rotation but overestimated the rotation degrees. The biases for overestimation from 3D imaging were smaller compared with 2D imaging at each LV level. Both methods, when compared with each other, showed a linear correlation ($r = 0.84$, $P < .0001$). Bland-Altman comparison showed 99% of data points within range, with a constant bias between both methods (adjusted values of 3D = 1.892 + 0.964 × 3D).

Conclusions: Although 3D echocardiography showed smaller bias, the results between 2D and 3D echocardiography were comparable. (J Am Soc Echocardiogr 2012;25:121-8.)

Keywords: LV twist, Validation study, 3D echocardiography

Left ventricular (LV) twist is suggested as an important index of contractility and a potential marker of myocardial dysfunction in the diseased heart. As an index of systolic function, LV twist is computed from the net difference of counterclockwise apical and clockwise basal LV rotation during systole.[1-4] Rapid unwinding of this systolic twist has also been shown to have significant contribution in early diastolic filling.[5-8] An accurate quantification of twisting LV motion, therefore, can provide important information about both systolic and diastolic function of the heart.

A noninvasive imaging-based assessment of LV twist is of significant resource in the clinical evaluation of dynamic LV function. With the introduction of digital tracking of speckles in ultrasound image loops, high–frame rate two-dimensional (2D) echocardiography was tested for the computation of LV twist from short-axis (SAX) views and validated.[9-11] However, selection of optimal imaging planes for such computation is quite challenging, because of limited acoustic windows and oblique orientation of the heart in the patient's chest cavity. Despite an accurate assessment of LV rotation with speckle tracking, the out-of-plane myocardial motion during 2D acquisition is a major source of error, especially near the LV base.

More recently, three-dimensional (3D) echocardiography has been introduced and is rapidly being integrated in clinical imaging because of its enhanced display of cardiac anatomy. New-generation matrix transducers have allowed the sequential acquisition of scan-line data with electrocardiographic gating and the reconstruction of 3D loops with a programmable degree of overlapping between successive volumes to suppress the through-plane motion, with resolution high enough to track speckle motion through the volumes for the computation of mechanical functions. The ability to obtain a full-volume image loop with a single acquisition from the same level and analyze the same volume at multiple levels avoids many difficulties of 2D echocardiographic methods. Digital feature tracking has also been tested to compute LV twist from high–frame rate 3D echocardiographic image loops and validated against sonomicrometry.[12,13] We

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Abbreviations
LV = Left ventricular
SAX = Short-axis
3D = Three-dimensional
2D = Two-dimensional
WMT = Wall Motion Tracking

sought to compare both 2D and 3D echocardiographic methods to quantify LV rotation at different levels using a custom-designed phantom.

METHODS

Heart Model

A two-axis linear/rotary torsion system was designed using rotary stepper motors to achieve both linear and rotary motion synchronized to each other, simulating base-to-apex linear and twisting cardiac motion. The rotary stepper motors were controlled using a six-step switching technique to allow for discrete commutation of the rotor and precision control of the position of each of the axis. An Atmel AT90CAN128 microcontroller (Atmel, San Jose, CA) was used to control the stepper motors and provide a digital interface (Figure 1). We studied 10 freshly harvested pig hearts. Each heart was mounted on the rotary actuator, with the base being rotated and the apex held fixed to avoid translational motion but permitting rotation. A pulsatile pump was connected to a balloon inserted into the LV cavity, and its rate of pumping was synchronized with the rate of rotation and linear motion. With each counterclockwise rotation as viewed from the LV apex, the base moved linearly toward the apex, which was held fixed, and the heart was emptied by synchronized negative suction of the pulsatile pump. The heart was filled with a positive upstroke of the pump with a known stroke volume and was synchronized with apex-to-base lengthening and clockwise untwisting, as viewed from LV apex. An electrocardiographic signal from the pulsatile pump was used to synchronize the pumping and torsion system. Linear motion of the torsion system was set to 20% of LV length for each heart. We studied different degrees of rotation (10°, 15°, 20°, and 25°) at a constant rate of 60 beats/min and stroke volume of 50 mL.

Data Acquisition

Full-volume 3D images were acquired from an apical window using a Toshiba Applio Artida ultrasound system (Toshiba, Tokyo, Japan) at a rate >22 volumes/sec. Frequency was optimized at 3.5 MHz, and scan range angle was set to 70° × 70° over six beats gated by the electrocardiographic signal generated from the pulsatile pump to acquire a complete dynamic image loop with uniform resolution quality throughout the depth of image. We used a Toshiba ultrasound system for the acquisition of 3D data sets, because it was the only system with released software to analyze 3D image loops for LV rotation at the time of the study. Similarly, a GE Vivid 7 Dimensions ultrasound system (GE Healthcare, Milwaukee, WI) was used to acquire 2D SAX views at two different LV levels with a 10S probe. The frame rate of acquisition was set at 80 to 90 frames/sec, and frequency was optimized to achieve uniform resolution quality throughout the depth of the image. Apical 2D SAX views were acquired from a distance equal to 20% of LV length from the apex, and basal 2D SAX views were acquired from a similar distance from the base of the heart. We used the GE Vivid 7 system for the acquisition of 2D data sets because a majority of published studies of LV rotation and twist have used this system.

Analysis

The 3D image data were analyzed for LV rotation using the new speckle tracking–based motion-detecting Wall Motion Tracking

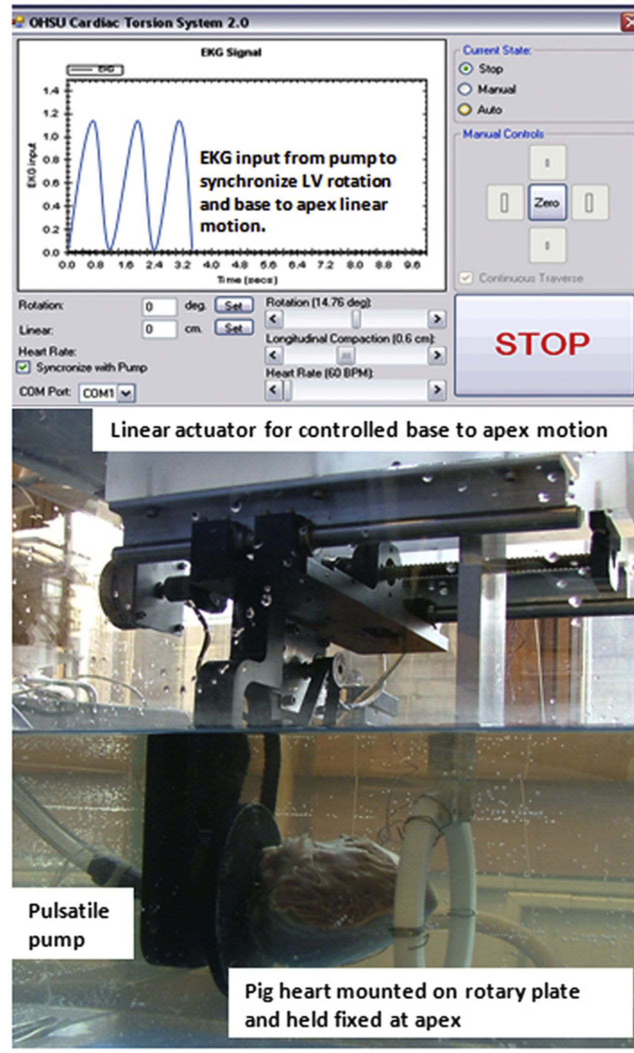

Figure 1 The model used in this study and a screen shot of the digital controls of the device. A freshly harvested pig heart is mounted on the rotary plate through the LV base with the apex stabilized and connected to a pulsatile pump through a balloon secured in the LV cavity. The digital interface was used to synchronize rotational, linear, and pulsatile motion to simulate physiologic motion of heart.

(WMT) program from Toshiba. One cycle of complete rotation and reversed motion was selected for resolution quality and complete inclusion of the LV wall. The WMT program shows 3D image data in two long-axis and three SAX 2D views that correspond to conventional two-chamber and four-chamber and parasternal SAX views (basal, middle, and apical). The program allows users to adjust the orientation of these 2D planes and draw an initial contour to define endocardial and epicardial borders on both long-axis views at the reference end-diastolic frame (Figures 2A and 2B). SAX planes are created by spline interpolation. The center of gravity of each SAX plane is created from the average of points defining SAX contour, and rotation center is defined by the center of gravity of each SAX plane in each frame. The software divides the LV wall into 16 segments and computes the degree of rotation globally and for each segment automatically, while tracking apex-to-base longitudinal motion (Figure 2). We computed planar rotation for the LV base and apex