Novel Velocity Vector Imaging Ultrasound Technique Demonstrates Asymmetric Deformation in the Normal Aortic Root

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Background

Previous models of the aortic valve function postulated motion based on pressure differentials. However, the aortic valve is an intricate hemodynamic system that rivals the mitral valve in complexity.

Animal studies have demonstrated that the aortic root undergoes complex, asymmetric deformations during the cardiac cycle.1The deformations are non-linear and include elongation and compression as well as shear and torsional deformations. The aortic root cusps are not uniform in size and the annular support varies.

In the present study, we investigated differences in aortic root regional strain on normal volunteers using a novel angle independent B-mode motion technique.

Methods

Patient selection:

We prospectively studied 15 healthy volunteers with no history of heart disease. The mean age was 41±7yrs; 5 were male. All subjects included in this report were in good health, had technically adequate short axis 2D images of the aortic root and were in normal sinus rhythm. One volunteer was excluded because of technically limited short axis images.

All participants gave written, informed consent, and study protocol was approved by the IRB at the hospital of the University of Pennsylvania.

Echocardiography protocol:

All the echocardiographic examinations were performed by using an Acuson Sequoia C512 ultrasound platform (Siemens).
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Subjects underwent a standard 2D echocardiographic examination to exclude undiagnosed cardiac disease.

Digital loops of the aortic root in the parasternal short axis were acquired at a high frame rate (>140Hz) for optimal temporal resolution. Normal studies were converted to 30 frame per second in DICOM format. We recorded cine loops using acoustic capture in " full information" format directly from the ultrasound machine on MO disk for off-line analysis. This avoided the loss of temporal resolution with DICOM conversion.

Disclosure:
- The following authors have nothing to disclose with relation to this presentation: Bettina B. Kuersten MD, Hind W. Rahmouni MD, Martin G.St John Sutton and Susan E. Wiegers MD.
- Joan C.Main and John Davidson are Siemens employees.

Off-line analysis

- Digital loops of the aortic root (Aor) in parasternal short axis were stored for off-line analysis. All the clips were analyzed using commercially available software Axius™ "Velocity Vector Imaging (VVI) "(Siemens Medical Solutions).

- VVI is an angle independent algorithm to evaluate strain and velocities. It uses whole heartbeat analysis using Fourier techniques as well as constraints on the global coherence of the tracked geometry.

- It uses 3 orders of refinement to track cardiac tissue
  1. It first tracks reference points and the motion of adjacent points is scaled based on the motion of the reference points.
  2. At the second order of refinement, it tracks the tissue/cavity border, using local correlations and snake contouring.
  3. At the third order of refinement, the speckles are tracked along the direction of the border.

- At each level, tracking is initially done over a 2 cm band, and then refined over successively smaller bands down to 5 pixels. This software allows the points of interest to be manually set. The tracking algorithm is automatically applied to a set of points on a contour in a sequence of two dimensional sequences of B-mode images. The velocity is displayed as a vector overlaid on the B-mode image. The length and direction of the tracking arrows reflects the magnitude and direction of the velocity vector at that point. Application of this method to an entire R-R interval provides a "real time" display of cardiac tissue motion.
- We set 1 point per coronary cusp segment (image1): [1 at the left coronary cusp (LC), 1 at the right coronary cusp (RC) and 1 at the non coronary cusp (NC). We added 3 additional points. One at each commissure.

- Circumferential strain was calculated at each frame time point and displayed on a strain curve (image 2). For each patient we also calculated the mean strain during systole for each region.

Statistics

Data are expressed as mean ±SD. Student t test was used for comparisons. A value of $P < 0.05$ was considered significant.

Results

We obtained good quality short axis images that could be analyzed in 15 out of 16 patients. We achieved a frame rate of > 140 in all patients with a range of 140 to 181Hz.
During systole, the regional strain was negative, indicating shortening in the right coronary cusp (RC) while both the left (LC) and non-coronary cusps (NC) lengthened.

1.Regional strain was RC: -21.6 ±24.2%, LC: 20.6 ± 20.4%,NC: 18.7 ± 13.4 %. (Figure 2,3)

2.Various regions of the aortic root had significantly different contributions to the overall change in luminal area. In all cases, regional luminal area increased in both LC and NC and decreased in RC regions

Image 1: Placement of the reference points

Image 3: Direction of the asymmetric motion of the aortic root.

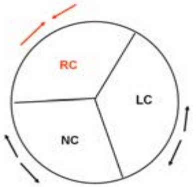
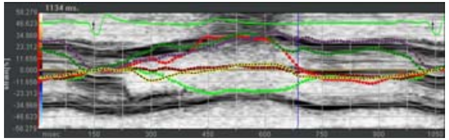
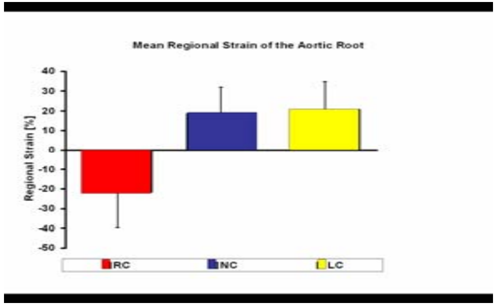


Image 2: Frame by frame circumferential strain at reference points. M-mode background allows assessment of timing of cardiac cycle.



Graph 1: Mean circumferential Strain at aortic cusps.(RC: Right coronary cusp,LC:Left coronary cusp, NC: Non coronary cusp)



Discussion

The concept of strain is complex, but linear strain can be defined by the Lagrangian formula:

$$\textbf{Strain} = L - L_0 / L_0$$

Where $L_0$is baseline length at time 0 and L is the instantaneous length at the time of measurement. By this definition, strain is a dimensionless ratio and is expressed in percent.

The term strain was first used in relation to the heart by Mirsky and Parmley to describe myocardial deformation.[2]Three modalities have been used to evaluate strain in relation to cardiac function.

1. SONOMICROMETRY: which is invasive and requiring placement of microcrystals at strategic points in the tissues being investigated and is confined to animal studies.
2. MRI tissue tagging: Relies on SPAMM technique (Spatial Modulation of Magnetization). While circumferential and radial strain can be analyzed, simultaneous functional information is not readily available. Furthermore, the technique cannot be applied to patients with pacemakers, AICD's, or other metal fragments.
3. Echocardiographic Tissue Doppler Imaging (TDI): Echocardiographic evaluation of strain remains limited because of the angle dependency inherent to the tissue Doppler technique .

VVI technique confirmed asymmetrical deformation of the Aor. During ejection, parts of the Aor contract while at the same time others dilate (image 3). Our results are consistent with previous animal studies demonstrating that the coronary cusps have different patterns of motion.[1]Opening of aortic valves is a dynamic process. Complex aortic root deformation possibly minimizes aortic cusp stress.

This is the first time that non-uniform deformation could be demonstrated by echocardiography, which makes motion and deformation of the Aor readily accessible to further study in cardiac and aortic pathology

Conclusions

More precise knowledge of aortic root dynamics may clarify the implications of various surgical procedures on long-term valve function and durability. New aortic valve repair techniques that best preserve this normal pattern of aortic root dynamics may translate into a lower risk of long term cusp deterioration.

References

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