Calculation of Mechanical Properties of the Inter-luminal Septum in DeBakey Type III Aortic Dissection from the Behavior of P-Waves Detected by cine MRI : Application of Seismic Technology onto Medical Image Data

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Introduction: High post-treatment mortality rates in DeBakey type III aortic dissections (AD) (20% in 3 years after hospital discharge [1]) necessitates a better understanding of biomechanical properties of true (TL) and false lumen (FL) wall tissue for the development of effective treatment. Similarly to any other elastic structure, the wall tissues of the aorta exhibit a specific dynamic response to the periodic excitation represented by the cyclic variation of the pressure. In an effort to create synergy between know-how in the energy industry and the medical community, we took advantage of established seismology techniques using the fact that the speed of propagation of a perturbation along an elastic system is directly related to the mechanical properties of the medium. From this, a first-order approximation of the stiffness of the AD intra-luminal septum was calculated by measuring the speed of the *wall-pressure-wave* from cine MRI images.

Methods: From 42 patients that underwent a dynamic MRI at the Acute Aortic Treatment Center at The Methodist DeBakey Heart & Vascular center, oblique axial (candy cane) cine MRI images (male, 70 years of age; steady state free precession, SSFP, implemented as TrueFISP, TR=40.2 ms, FOV= 375 x 500 mm, inplane resolution: 2mm, slice thickness 5 mm) from one patient was selected. The *wall-pressure-wave* was identified and its velocity calculated (figure 1). The travelling speed of a P-wave, c_p, is directly related to the Young modulus as $c_p = \sqrt{\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}}$. The effective Young modulus E is defined as the ratio between the elastic deformation ε and the stress σ. For the specific case of the dilation of a circular cross section of the aortal walls, the stress is represented by the internal pressure and the deformation is the stretching in the tangential direction. Thus, the actual Young modulus of the wall tissues can be directly calculated from the effective Young modulus associated with such pressure wave.

Results: The measured c_P was 1.21 m/sec based on a time lag of 301.5 ms for the wave to travel along a curvilinear distance of 36.7 cm. This value has to be compared to the PWV reported for healthy older individuals (64.7 ± 10 years) of 8.08 ±2.18 m/sec and a reported Young's modulus E of 126 ± 57 kPa for that velocity range [2]. As E depends on the square of PWV, Young's modulus for the AD septum can be estimated to be about a factor of 45 lower.

Conclusions: Clearly, the assumption imposed by this novel methodology are significant, including the elastic behavior of the wall over large deformations, the first-order approximation of the relation between traveling speed and Young modulus, and the homogeneity of the tissues properties. However, further verification against the actual mechanical properties may assess the validity of a new, non-invasive estimate of tissues' stiffness.

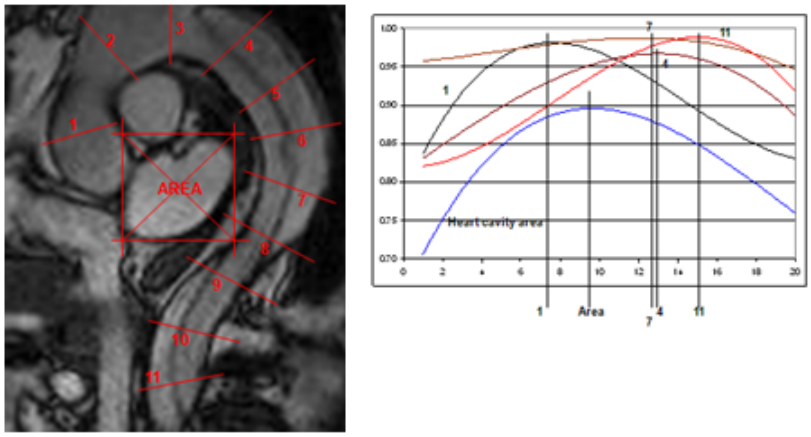

Figure 1: *Left:* Sagittal cine image with locations marked where wall extension was measured (on right). *Right:* Luminal extension (a.u.) for different frames (TR=40.2 ms). A clear time delay can be measured from location 1 to 11 from frame 15 to frame 7.5 (x axis) corresponding to 301.5 ms.

References

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2. Yu HY, Peng HH, Wang JL, Wen CY, Tseng WY. Quantification of the pulse wave velocity of the descending aorta using axial velocity profiles from phase-contrast magnetic resonance imaging. Magn Reson Med 2006;56(4):876-883.