The Role of Ultrasound in Electro-Mechanical Coupling

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***Abstract*— This writing and the subsequent oral presentation are dedicated to my friend and colleague, Robert Plonsey. Professor Plonsey first introduced me to the researchers at the Ragnar Institute and made me more fully aware of the theoretical aspects of electrophysiology. Our discussions frequently turned to the question of how ultrasound imaging may help identifying conduction problems. Ultrasound, because of its real time nature, is ideally suited for quantifying mechanical indexes of cardiac performance. Certainly our early work at Duke focused on evaluating cardiac structures, such as valves, and calculating ejection fractions from two dimensional images.**

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I. Introduction

In recent years as improved echocardiographic scanners and high performance computing methods have become more readily available attention has focused to a more detailed investigation of dyssynchronous cardiac wall motion. This interest was spurred by the one third failure rate of implanted biventricular pacers, an expensive yet revolutionizing advance in the treatment of heart failure. Cardiac Resynchronization Therapy or CRT reduces diastolic LV dimension and improves ejection fraction in those patients when CRT is successful. About 15% of Congestive Heart Failure patients are candidates for CRT.

II. Material and Methods

The ultrasound method that has become important in identifying patients most likely to benefit from CRT is based in measuring myocardial contraction and motion in small connected regions or segments of the entire LV wall. This so called “strain analysis” can be resolved into directional motion components such as circumferential motion, circumferential strain, and strain along the heart wall or longitudinal strain. At this time most clinical measurements rely on longitudinal strain measurements. In normal contraction all segments of the LV wall contract at about the same time during systole and the filling phases during diastole are also synchronous. In various pathologic conditions such as post infarction or left bundle branch block, one or more LV segments tend to dilate early in systole and contraction is delayed post aortic valve closure. Also the dilation strain curves during diastole are affected in many LV segments. In those patients that respond positively to CRT the normal pattern of longitudinal strain curves is restored throughout the cardiac cycle.

These ultrasonic strain analyses are also finding important applications in post transcatheter aortic valve implantation follow ups. Since the aorta is anatomically close to the left bundle, 30% of TAVI patients experience LBBB post interventions. These patients usually show the classical dyssynchrony strain profiles and are excellent candidates for CRT.

In current ultrasound strain studies the time resolution of ultrasound data is between 10 to 30 milliseconds. For a more accurate investigation of the electromechanical coupling events, it is desirable to obtain ultrasound samples at rates commensurate with EKG signals. Since the recommended rate for clinical EKG is 500 Hz and above it follows that ultrasound images should be acquired at that rate. Recently, we have modified our experimental Duke Phased Array Scanner to permit imaging at rates up to 2500 per second depending on the application. For adult echocardiography typical frame rates range from 500 to 1000 Hz, significantly faster than the 30 to 100 Hz frame rates of conventional scanners.

III. Future Studies

In future studies the challenge will be to fully exploit these frame rates. Methods need to be developed to display changes in myocardial impedances as muscle fibers stiffen and relax associated with electrical events. Ultrasound studies applying Shear Wave Imaging have shown that the myocardial elastic modulus changes by a factor of ten throughout the cardiac cycle. Improved image quality at high ratesw will also be important to make high speed imaging a useful clinical technique. If we meet these objectives, high speed imaging will open new avenues for studying the heart in disease and health.