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● *Original Contribution*

ASSESSMENT OF DIASTOLIC FUNCTION USING ULTRASOUND ELASTOGRAPHY

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Abstract—Shear wave elasticity imaging (SWEI) is a novel ultrasound elastography technique for assessing tissue stiffness. In this study, we investigate the potential of SWEI for providing diastolic functional assessment. In 11 isolated rabbit hearts, pressure-volume (PV) measurements were recorded simultaneously with SWEI recordings from the left ventricle free wall before and after induction of global ischemia. PV-based end diastolic stiffness increased by 100% after ischemia ($p < 0.05$), and SWEI stiffness showed an increase of 103% ($p < 0.05$). The relaxation time constant (τ) before and after ischemia derived from pressure and SWEI curves showed increases of 79% and 76%, respectively ($p < 0.05$). A linear regression between pressure-derived and SWEI-based (τ) showed a slope of 1.164 with $R^2 = 0.80$, indicating the near equivalence of the two assessments. SWEI can be used to derive (τ) values and myocardial end diastolic stiffness. In global conditions, these measurements are consistent with PV measurements of diastolic function. (E-mail: patrick.wolf@duke.edu)

Key Words: **Shear wave imaging, Elastography, Diastolic function, HFpEF, Lusitropy, Isovolumic relaxation time constant.**

INTRODUCTION

Heart failure with preserved ejection fraction (HFpEF) is a major cause of death, affecting approximately 3 million diagnosed patients in the United States. It has been shown that approximately 81% of HFpEF patients experience diastolic dysfunction (Writing Group Members et al. 2016). Diastolic dysfunction is defined as the inability of the ventricle to receive a sufficient amount of blood during diastole. Histologic studies have shown that myocardial hypertrophy, increased interstitial disposition of collagen and infiltrative mechanisms yield stiffer cardiac tissue (Jeong and Dudley 2015). These processes affect the active relaxation and passive myocardial properties, deteriorating ventricular relaxation and the compliance of the heart. The isovolumic relaxation time constant (τ) and ventricular stiffness (inverse compliance) values have been proposed as two major indices for assessment of diastolic function (Burkhoff et al. 2005; Gross 2009; Jeong and Dudley 2015). These indices are derived experimentally from intra-ventricular pressure-volume (PV) recordings, considered to be the gold standard technique; however, this method requires an invasive procedure and is not used routinely in the clinic.

In clinical practice, the presence of a combination of factors is used to determine the diagnosis of diastolic heart failure, including the presence of the signs and symptoms of heart failure, normal ejection fraction and increased diastolic pressure or impaired filling of the ventricle (Jeong and Dudley 2015). Echocardiography and Doppler imaging usually are used for assessment of diastolic function. However, these measurements can be normal in some conditions during the intermediate stages of diastolic dysfunction, an occurrence referred to as *pseudonormalized measurements* (Oh et al. 2011). Recently, speckle-tracking echocardiography and strain analysis have been used to track myocardial wall motion during the cardiac cycle (Dusch et al. 2014). These measurements are usually load dependent and do not provide a direct measurement of tissue stiffness or of the relaxation time constant. In addition, valvular disorders and irregularities in heart rhythm that could change the atrial mechanics, such as atrial fibrillation, can affect the accuracy of these measurements (Vorovich et al. 2014). Therefore, it is of great importance to develop a non-invasive technique that can provide direct diastolic functional indices of the myocardium analogous to the PV-derived indices.

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Ultrasound-based elasticity imaging has been developed recently to measure the static stiffness of tissues (Doherty et al. 2013; Greenleaf et al. 2003). This technique can be thought of as palpating the tissues virtually using ultrasound. To implement this technique, an acoustic radiation force impulse (ARFI) is generated, which pushes the desired location of the tissue and generates shear waves. The propagation of these waves in the perpendicular direction is tracked. This technique is called shear wave elasticity imaging (SWEI). The velocity of the propagating shear waves is proportional to the stiffness of the tissue (Doherty et al. 2013). SWEI is now being used in the clinic to detect changes in tissue stiffness to detect fibrosis or lesions in the liver (Doherty et al. 2013).

Recent studies have shown the feasibility of using SWEI to record the dynamic stiffness in the heart (Pernot et al. 2011, 2016; Pislaru et al. 2014; Vejdani-Jahromi et al. 2016). An example of the dynamic stiffness changes during the cardiac cycle is illustrated in Figure 1. The value of these methods in assessing ablation treatments has been previously shown (Eyerly et al. 2015; Kwiecinski et al. 2014). In addition, multiple researchers have shown the feasibility of transthoracic SWEI measurements in human patients (Correia et al. 2016; Kakkad et al. 2015; Song et al. 2016; Strachinaru et al. 2017), raising the possibility of a completely non-invasive method of cardiac diastolic functional analysis.

Important to the clinical translation of SWEI is an understanding of this new measure in terms of existing measures of the functional properties of the heart during systole and diastole, including the compliance, the relaxation time constant and the contractility of the heart. In our previous studies, we have shown the potential of this technique to measure cardiac contractility and cardiac compliance using the coronary perfusion pressure (garden hose/turgor and Gregg) effects on cardiac function (Vejdani-Jahromi et al. 2015, 2017). Moreover, in our earlier work, we showed that the relaxation time constant (τ) can be derived from SWEI measurements during the cardiac cycle (Vejdani-Jahromi et al. 2016).

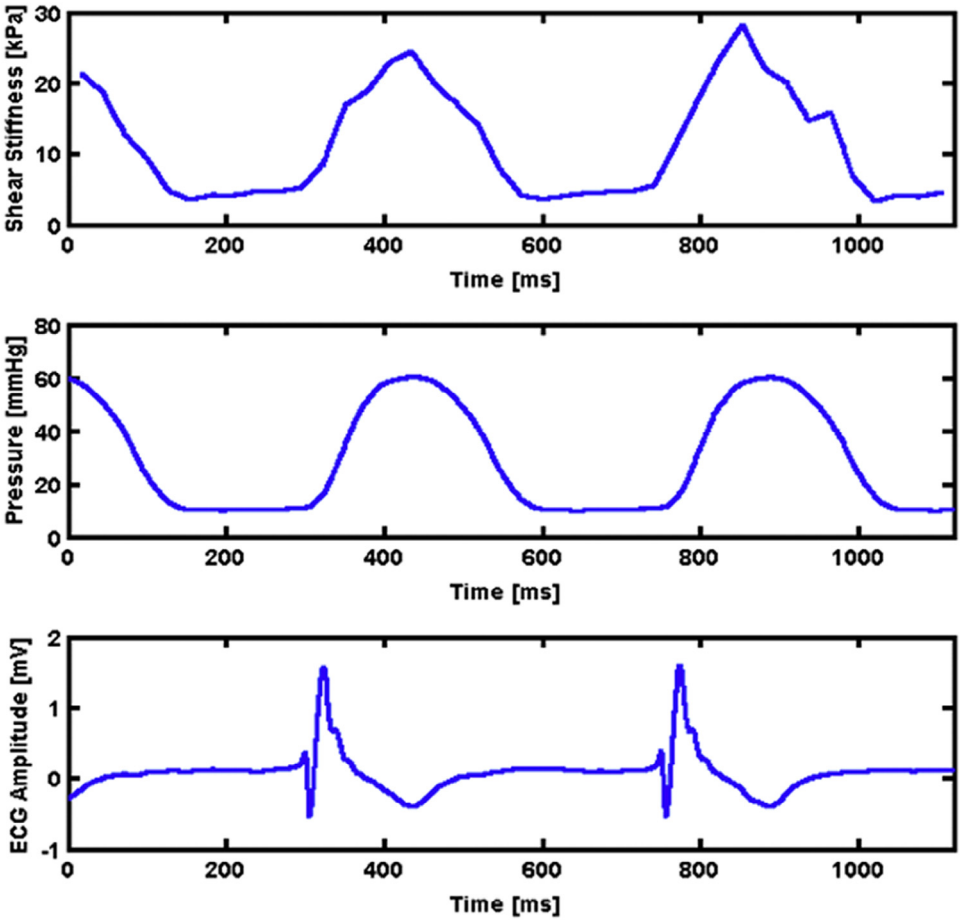

Fig. 1. The dynamic stiffness (shear modulus) changes during the cardiac cycle recorded by SWEI (*top panel*). The simultaneous intra-ventricular pressure recordings recorded by PV catheter (*middle panel*). The echocardiogram signal (*bottom panel*). SWEI = shear wave elasticity imaging; PV = pressure volume.