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● *Original Contribution*

MYOCARDIAL STRAIN RATE BY ANATOMIC DOPPLER SPECTRUM: FIRST CLINICAL EXPERIENCE USING RETROSPECTIVE SPECTRAL TISSUE DOPPLER FROM ULTRA-HIGH FRAME RATE IMAGING

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Abstract—Strain rate imaging by tissue Doppler (TDI) is vulnerable to stationary reverberations and noise (clutter). Anatomic Doppler spectrum (ADS) presents retrospective spectral Doppler from ultra-high frame rate imaging (UFR-TDI) data for a region of interest, that is, ventricular wall or segment, at one time instance. This enables spectral assessment of strain rate (SR) without the influence of clutter. In this study, we assessed SR with ADS and conventional TDI in 20 patients with a recent myocardial infarction and 10 healthy volunteers. ADS-based SR correlated with fraction of scarred myocardium of the left ventricle ($r = 0.68, p < 0.001$), whereas SR by conventional TDI did not ($r = 0.23, p = 0.30$). ADS identified scarred myocardium and ADS Visual was the only method that differentiated transmural from non-transmural distribution of myocardial scar on a segmental level ($p = 0.002$). Finally, analysis of SR by ADS was feasible in a larger number of segments compared with SR by conventional TDI ($p < 0.001$). (E-mail: Lars.c.nilsen@ntnu.no) © 2017 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Strain rate, Deformation imaging, Infarct diagnostics, Tissue Doppler imaging, Regional myocardial function, Retrospective spectral tissue Doppler, Anatomic Doppler spectrum, Ultra-high frame rate tissue Doppler imaging, Ultrafast cardiac imaging.**

INTRODUCTION

Regional myocardial function is important in assessment of coronary artery disease (Montalescot et al. 2013). The introduction of tissue Doppler imaging (TDI) (Isaaz et al. 1989) enabled estimation of myocardial velocities. Peak annular velocities proved to be a useful prognostic tool in patients with cardiovascular disease (Hoffmann et al. 2011). Tissue velocities are suitable for estimation of global myocardial function; however, as contracting myocardium will cause the neighboring tissue to move because of tethering (Heimdal et al. 1998b), differentiation between active and passive motion is a challenge. Such a limitation renders tissue velocity estimates less suitable for evaluation of regional myocardial function. This motivated the introduction of deformation imaging for quantification of regional left ventricular function (Heimdal et al. 1998b; Smiseth et al. 2004; Stoylen et al. 1999; Urheim et al. 2000; Voigt et al. 2000).

Strain and strain rate (SR) by TDI quantify relative wall deformation, that is, shortening and lengthening, and can be used for evaluation of regional myocardial function. As SR is an estimate of wall deformation rather than wall motion, it subtracts the effects of tethering (Heimdal et al. 1998a). SR is therefore more suitable for evaluation of regional function and viability than tissue velocities alone (Gjesdal et al. 2008; Jamal et al. 2001; Kaluzynski et al. 2001; Weidemann et al. 2003). SR can be estimated from tissue velocities by the velocity gradient in a given segment (Fleming et al. 1994) and represents deformation per unit of time.

The new Doppler acquisition method, ultra-high frame rate tissue Doppler imaging (UFR-TDI)

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(Brekke et al. 2014), enables acquisition of TDI data at a frame rate of 1200 frames/s. The method allows retrospective extraction of spectral TDI data from two ventricular walls simultaneously in an apical view (Figs. 1c and 2). Consequently, the Doppler spectrum along the ventricular wall from a given time point can be visualized in an anatomic Doppler spectrum (ADS) (Fig. 2c). This enables analysis of the spatial distribution of tissue velocities, that is, the velocity gradient along the ventricular wall, by tracing the spectral envelope in ADS (Fig. 2). The velocity gradient can be expressed as shortening per unit of time, that is, SR (Sagberg et al. 2004), and can be visualized and measured with ADS. As ADS allows visualization of the Doppler spectrum, it also enables separation of clutter and signal in the same manner as pulsed wave (PW) spectral Doppler (Fig. 1b). Because clutter will appear as low velocities near zero, signal can easily be separated from noise by ADS (Fig. 2), allowing estimation of SR without the influence of clutter. This potentially overcomes some of the limitations of SR from conventional TDI, which is vulnerable to noise and suffers from high variability (Ingul et al. 2005) caused by stationary reverberations (clutter) (Aase et al. 2008) (Fig. 3).

The aims of this study were therefore to investigate if SR by ADS can be used for detection of myocardial scar in patients who have had a myocardial infarction and to compare the number of segments feasible for analysis with ADS and conventional TDI. We also compared mitral annular velocities measured by ADS and PW spectral Doppler. Finally, we correlated our findings with myocardial scar detected with late gadolinium-enhanced magnetic resonance imaging (LGE-MRI).

METHODS

Study population

Ten healthy volunteers and 20 patients at least 3 wk past their first ST-elevation myocardial infarction (MI) were subsequently enrolled in the study. The inclusion criteria were age <75 y, peak troponin T > 1000 ng/L, estimated glomerular filtration rate >60 mL/min and New York Heart Association functional class <III. Exclusion criteria were previous MI, contraindications to MR contrast/ultrasound contrast, severe heart failure and chronic atrial fibrillation. No patients were excluded for poor echocardiographic quality. One patient was excluded from the analysis as the patient could not complete the LGE-MRI examination because of claustrophobia. All patients had been examined with acute coronary angiography, and percutaneous coronary intervention (PCI) was performed in all patients as appropriate during the acute phase. The control group consisted of 10 healthy volunteers. The control group was not examined with LGE-MRI. Population characteristics are outlined in Table 1. Informed consent was obtained from all study participants. The study was approved by the regional ethics committee for medical research ethics and conducted according to the Helsinki Declaration.

Echocardiographic acquisition

All echocardiographic data were acquired by experienced sonographers using a Vivid E9 with a M5S-D probe (GE Vingmed Ultrasound AS, Horten, Norway), and data were acquired from the three apical views (two-chamber, four-chamber and apical long-axis). Conventional TDI was analyzed in Echopac 112 (GE Vingmed Ultrasound AS).

Ultra-high frame rate tissue Doppler imaging

Ultra-high frame rate tissue Doppler imaging data were analyzed with in-house developed software in MATLAB 2011a (The MathWorks, Natick, MA, USA). UFR-TDI acquires TDI data at 1200 frames/s. The setup uses two wide transmit beams to cover the ventricular walls from the apical view. The transmit beams cover the two 20° outermost subsectors of the acquired sector. The sector width was manually adjusted to cover the left ventricular walls within the two subsectors.

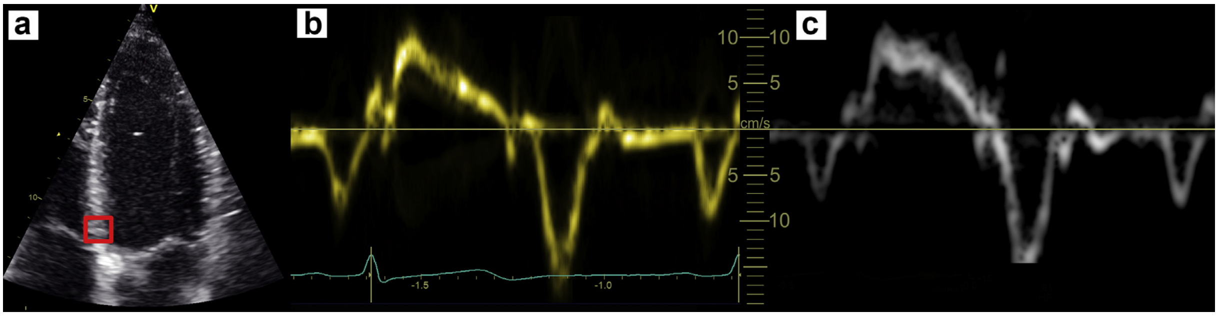

Fig. 1. (a) B-Mode with sample volume. (b) Conventional pulsed wave tissue Doppler from sample volume in (a). (c) Retrospective spectral Doppler from ultrahigh-frame-rate tissue Doppler imaging data from sample volume in (a).