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## Original Contribution

# SWAVE IMAGING OF PLACENTAL ELASTICITY AND VISCOSITY: PROOF OF CONCEPT

Jeffrey M. Abeysekera,*† Manyou Ma,* Mehran Pesteie,* Jefferson Terry,‡ Denise Pugash,§ Jennifer A. Hutcheon,¶ Chantal Mayer,‡ Lutz Lampe,* Septimiu Salcudean,* and Robert Rohling*†

* Department of Electrical and Computer Engineering, University of British Columbia, Vancouver, British Columbia, Canada; † Department of Mechanical Engineering, University of British Columbia, Vancouver, British Columbia, Canada; ‡ Children's & Women's Health Centre of British Columbia, Vancouver, British Columbia, Canada; § Department of Radiology, University of British Columbia, Vancouver, British Columbia, Canada; and ¶ Department of Obstetrics and Gynaecology, University of British Columbia, Vancouver, British Columbia, Canada

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**Abstract—The placenta is the interface between the fetus and the mother and is vital for fetal development. Ultrasound elastography provides a non-invasive way to examine *in vivo* the stiffness of the placenta; increased stiffness has previously been linked to fetal growth restriction. This study used a previously developed dynamic elastography method, called shear wave absolute vibro-elastography, to study 61 post-delivery clinically normal placentas. The shear wave speeds in the placenta were recorded under five different low-frequency mechanical excitations. The elasticity and viscosity were estimated through rheological modeling. The shear wave speeds at excitation frequencies of 60, 80, 90, 100 and 120 Hz were measured to be 1.23 ± 0.44, 1.67 ± 0.76, 1.74 ± 0.72, 1.80 ± 0.78 and 2.25 ± 0.80 m/s. The shear wave speed values we obtained are consistent with previous studies. In addition, our multi-frequency acquisition approach enables us to provide viscosity estimates that have not been previously reported. (E-mail: rohling@ece.ubc.ca) © 2017 World Federation for Ultrasound in Medicine & Biology.**

*Key Words:* **Placenta, Shear wave, Shear wave absolute vibro-elastography, SWAVE, Ultrasound elastography, Young's modulus.**

## INTRODUCTION

Elastography is a technique for imaging the mechanical properties of tissue, including shear wave speed ($c_s$), shear modulus ($\mu$) and Young's modulus ($E$). Elastography has been found to have potential in imaging soft tissues such as the breast, prostate, liver (Gennisson et al. 2013) and, more recently, placenta (Cimsit et al. 2015a, 2015b; Kılıç et al. 2015; Li et al. 2012; McAleavey et al. 2016; Ohmaru et al. 2015; Sugitani et al. 2013; Wu et al. 2016). Histology indicates that abnormal placental structure, such occurs in growth-restricted pregnancies, is significantly different from normal placenta and is suggested as a cause of significant differences in mechanical properties (Lau et al. 2016). Elastography offers a non-invasive way of characterizing changes in mechanical properties *in vivo*. For example, preliminary studies have found a significant increase in placental shear modulus for patients with pre-eclampsia (Cimsit et al. 2015a; Kılıç et al. 2015; Ohmaru et al. 2015) and fetal growth restriction (Ohmaru et al. 2015).

Elastography consists of applying an exciting force to the tissue, measuring the resulting tissue motion and calculating one or more mechanical properties from the measurements. A common variation uses multiple *high-intensity* acoustic radiation force impulses (ARFIs) and measures the shear wave speed $c_s$ using pulse-echo ultrasound. Shear wave speed can be derived from biomechanics principles under certain modeling assumptions. For example, the shear wave speed $c_s$ in homogeneous and isotropic tissue is related to the shear modulus $\mu$ via $\mu = \rho c_s^2$, where $\rho$ is tissue density. Furthermore, if it is assumed that human soft tissue is nearly incompressible, $E \approx 3\mu$. These relations allow tissue elasticity to be displayed as a color map with colors corresponding to absolute values of either shear wave speed, in meters

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Address correspondence to: Robert Rohling, Department of Electrical and Computer Engineering, University of British Columbia, Vancouver, BC V6T1Z4, Canada. E-mail: rohling@ece.ubc.ca

per second, or elastic modulus, in kilopascals. These relations also allow the values from different systems to be compared, acknowledging that differences in methodology and tissue models also affect the values.

For imaging of the placenta, ARFI-based elastography techniques are promising, but more studies are needed to establish the utility and safety of these techniques (Gandhi et al. 2015). An inherent limitation of using ARFI is the depth of penetration. Depth is reportedly limited with one ARFI-based elastography system to 5.5 cm (D'Onofrio et al. 2010). A study with another ARFI-based elastography was unable to study placentas located at depths greater than 8 cm (Cimsit et al. 2015a). This prohibits imaging of posterior-located placentas and obese patients, creating a technical limitation for the use of ARFI-based elastography in generalized screening of placental disorders. Furthermore, ARFI acquisition for multiple planes may have additional deleterious effects, such as heating of the ultrasound transducer face.

There is a need for an elastography technique that can measure absolute values of the mechanical properties of the placenta in both superficial and deep locations. In this article, we describe an elastography system that meets this criterion, called shear wave absolute vibro-elastography (SWAVE). SWAVE is an implementation of elastography that provides maps of mechanical properties in absolute units. SWAVE has also been performed on breast (Eskandari et al. 2013) and prostate (Salcudean et al. 2012) tissue *in vivo*. SWAVE has been performed in the liver with deep (>15 cm) measurements (Baghani et al. 2012). Among the variety of elastography methods in the literature (Gennisson et al. 2013; Mariappan et al. 2010), SWAVE is most similar to magnetic resonance elastography because they both use *low-frequency* steady-state mechanical waves to excite tissue, measure the motion phasors and calculate a map of the elasticity distribution to match the motion measurements over a 3-D region of interest (ROI). Hereafter, the term *elasticity* is used as a generalized term for simplicity when appropriate.

To explore the feasibility of investigating the elasticity of the placenta for diagnostic purposes using the SWAVE system, we performed elasticity measurements on clinically normal placentas *ex vivo* and compared the measured shear wave speed with values obtained from previous ARFI-based studies. The analysis included an investigation of the relationship between the resulting shear wave speeds under different excitation frequencies in the context of visco-elastic tissue models.

## METHODS

In this section, we give a brief introduction of our customized SWAVE measurement system, including its software and hardware components. We then detail its elastography measurement method. The experimental setup for placenta measurements is also explained.

### *System overview*

The placenta data gathered in this experiment were obtained using a modular ultrasound scanning system. The system comprises an Ultrasonix SonixTouch ultrasound machine (Analogic, Richmond, BC, Canada), with a 3-D motorized probe (4DL14-5/38 Ultrasonix, Richmond, BC, Canada). A voice coil exciter (LDS V203, Brüel & Kjær, Nærum, Denmark) is used to apply vibrations to the surface of the placenta. The history and derivation of the system are described in Abeysekera (2016). Figure 1 outlines the essential components of the system used in this study.

The main software modules of the SWAVE system are the ultrasound interface module, which streams data and settings for the scanner and transducer; the motor control module, which collects volumetric data using the motorized ultrasound transducer through the Porta interface of the SonixTouch machine; the excitation control module, which programs the function generator and vibration shaker; and the elastography processing subsystem, which performs motion tracking and elasticity estimation. The components are integrated through a graphic user interface on the scanner, which also provides real-time display of B-mode images, tissue motion and elasticity images, as well as data saving for off-line use. The SWAVE software system was developed with Microsoft Visual C++ (Redmond, WA, USA). Modules for motion tracking, elasticity estimation, envelope detection and scan conversion were accelerated using the CUDA API (NVIDIA, Santa Clara, CA, USA).

One of the features of the SWAVE system is volumetric radiofrequency (RF) data collection with customized motor control, which is achieved using the motor and excitation control modules. The motor control module plugs into the transducer connector, passes through all imaging signals to an identical connector and bypasses the conventional motor control of the 3-D probe with one that is synchronized with the exciter. It provides motor commands to step the motor to a position, collects several frames and then steps the motor to the next position in the sweep. This sweep allows for measurements of tissue displacements with frequencies spanning 20–300 Hz, without any modification of the transducer or scanner.

To achieve deep tissue penetration, the SWAVE system applies a longitudinal vibration to the surface of the placenta with a small circular disk at the end of a rod, vibrating normally to the surface of the tissue. The exciter used in this study consisted of a 3-cm-diameter circular steel plate, which was placed in contact with the placenta on one end and attached at the other end to a 10-cm steel