Ultrasound in Med. & Biol., Vol. ■, No. ■, pp. 1–14, 2017

0301-5629/$ - see front matter

http://dx.doi.org/10.1016/j.ultrasmedbio.2017.06.008

● *Original Contribution*

PERFORMANCES AND LIMITATIONS OF SEVERAL ULTRASOUND-BASED ELASTOGRAPHY TECHNIQUES: A PHANTOM STUDY

Stéphanie Franchi-Abella,* Caroline Elie,† and Jean-Michel Correas‡

*Pediatric Radiology Department-Bicêtre Hospital, Hôpitaux Universitaires Paris-Sud- Assistance Publique Hôpitaux de Paris-Université Paris Sud, Le Kremlin-Bicêtre, France; †Clinical Research Unit-Clinical Investigation Centre-Necker Enfants-Malades Hospital–Université, Paris Descartes, Sorbonne Paris Cite, France; and ‡Adult Radiology Department- Necker Enfants-Malades Hospital–Université, Paris Descartes, Sorbonne Paris Cite, Paris, France

(*Received* 25 *July* 2016; *revised* 3 *June* 2017; *in final form* 5 *June* 2017)

Abstract—The objective of this study is to assess strain and shear wave (SW) elastography performance in terms of accuracy by performing *in vitro* measurements on a calibrated elastography phantom. Acquisitions were done on a phantom containing 4 inclusions (12–74 kPa) embedded in a homogeneous background material (30 kPa). We performed qualitative assessment on elastograms, semiquantitative assessment with strain or elasticity ratios between each inclusion and the background and quantitative evaluation with SW acquisitions. Ratio and elasticity estimations were compared with expected values. Biases, relative errors and 95% confidence intervals (95% CI) were calculated. All techniques adequately classified inclusions as harder or softer than the background. For stiffness ratio estimation, SW methods were more precise than strain methods and had significantly higher percentages of correctly classified measurements ($p = 0.008$). Quantitative stiffness measurements were reproducible despite constant biases. SW elastography methods provide more reproducible estimations of tissue stiffness ratio than strain methods, as well as reproducible quantitative tissue stiffness despite constant biases. (E-mail: stephanie.franchi@aphp.fr) © **2017 World Federation for Ultrasound in Medicine & Biology.**

Key Words: **Ultrasound, Elastography, Tissue elasticity imaging, Elasticity phantom, Shear wave elastography.**

INTRODUCTION

Pathologic processes can alter tissue stiffness (elasticity). Significant focus is on elastography techniques that permit non-invasive assessment of tissue stiffness using ultrasound (US) or magnetic resonance imaging (MRI).

Two different approaches are used for US elastography: strain elastography and shear wave (SW) speed measurement. The strain elastography principle relies on soft tissues' tendency to exhibit a higher deformation than stiffer regions when a distorting force is applied. External deformation is created by moving the transducer vertically over the tissue, creating intermittent pressure on the tissue (Ophir et al. 1991). Internal deformation can be generated either by internal tissue movement or by the imaging transducer itself by focusing the ultrasound beam and creating an acoustic radiation force impulse (ARFI) (Nightingale et al. 2002). Whatever the technique, relative stiffness of the tissue is displayed either on a gray-scale or a color-scale map (*i.e.,* strain elastogram). Qualitative visual scoring systems have been applied in clinical studies to characterize nodules. As strain elastography is not quantitative, methods of semi-quantification are proposed with the calculation of strain ratios between two structures. Clinical studies that have focused on mass characterization and liver fibrosis are available (Bhatia et al. 2010; Cho et al. 2012; D'Onofrio et al. 2010; Park et al. 2009; Sebag et al. 2010; Thomas et al. 2010; Wojcinski et al. 2010; Zhang et al. 2012; Zhi et al. 2010).

SW elastography (SWE) relies on the measurement of SW propagation speed in soft tissue and is a quantitative approach (Nightingale et al. 2002). The SW can be created either by an external piston applied on the skin (transient elastography [TE], FibroScan, Echosens, Paris France) or by ARFI (Virtual Touch Quantification [VTQ] and Virtual Touch Image Quantification [VTIQ], Siemens, Erlangen, Germany; point shear-wave, Royal Philips, Amsterdam, The Netherlands; SWE, Toshiba, Tokyo, Japan). SuperSonic Imagine shear wave elastography (SSWE,

Address correspondence to: Stéphanie Franchi-Abella, Service de radiopédiatrie-Hôpital Bicêtre, 78 rue du general Leclerc, 94275 Le Kremlin-Bicêtre, France. E-mail: stephanie.franchi@aphp.fr

SuperSonic Imagine [SSI], Aix-en-Provence, France) relies on the association of ultrafast US technology and creation of a Mach cone while creating the ARFI (Bercoff et al. 2004). For SW techniques, the results are provided as SW speed (measured as ms^{-1}) or tissue stiffness; indeed, the Young's modulus (measured in kPa) is related to the SW speed by a simple mathematical relationship. According to the US elastography technique, results are displayed with or without 2-D SW maps. Qualitative analysis is also possible if a 2-D SW map is available. Calculating ratios of stiffness between two regions of interest (ROIs) allows semiquantitative analysis. The strain and SW elastography techniques are extensively reviewed in the European Federation of Societies for Ultrasound in Medicine and Biology guidelines on the clinical use of US elastography (Bamber et al. 2013).

Despite extensive use of these methods reported in the literature, few phantom studies exist (Carlsen et al. 2014, 2015; Chang et al. 2013; Dillman et al. 2015; Fukuhara et al. 2014; Havre et al. 2008, 2011; Mulabecirovic et al. 2016; Mun et al. 2013; Shin et al. 2016). Most of the studies aim to evaluate the intra- and inter-observer reproducibility and the reliability of a single technique. Only three studies compared several SWE techniques in a single phantom. Dillman et al. (2015) evaluated the reproducibility of the measurement, the inter-operator agreement and the factors influencing measurements. Shin et al. (2016) studied the accuracy and repeatability of measurements, the influence of the system, the transducer and the acquisition depth on measurements. Recently Mulabecirovic et al. (2016) studied the intra- and inter-observer reliability of five US elastography systems (two using strain elastography and three based on SWE).

To our knowledge no previous report compares the accuracy of strain and SW methods (using qualitative, semiquantitative and quantitative analysis) in phantom studies. However, this is a necessary preliminary step to improve further utilization of elastography as a biomarker in clinical practice especially.

The aim of our study was to assess the performance of strain and SWE techniques in terms of accuracy by performing *in vitro* measurements using several available US elastography techniques on the same calibrated and commercially available elastography phantom.

MATERIALS AND METHODS

In *vitro setup and scanning protocol*

A single operator (S.F.A.) with more than 15 y of experience in ultrasound imaging and 4 y of experience in US elastography performed all acquisitions using a standardized scanning protocol on a calibrated tissue-mimicking phantom developed for elastography quality assessment (Elasticity QA Phantom model 049, CIRS Technology, Norfolk, VA, USA). Only the 4 shallowest inclusions of this phantom were scanned in this work. The phantom characteristics are presented in Figure 1, which also provides the mean elasticity ratio of each inclusion with the background (BG) and its range (BG). All measurements were performed within a 9-mo period.

Five US diagnostic imaging systems with the most recently available elastography software versions were used in this study: MyLab Twice, Esaote, Genoa, Italy; HI VISION Prerius, Hitachi Medical Corporation, Tokyo, Japan; iU22, Philips Healthcare, Andover, MA, USA; ACUSON S3000, Siemens HealthCare, Issaquah, WA, USA; Aixplorer, SuperSonic Imagine, Aix-en-Provence, France (Table 1). Note that Toshiba SW methods were unavailable at the time of the study. For each manufacturer, a linear transducer supporting elastography capabilities was selected (with frequencies ranging 4 MHz–18 MHz). The scanning technique was adapted to each elastography technology. For quasistatic elastography, the deformation was induced by either external pressure-release cycles applied with the transducer (Elaxto, Esaote; HI-RTE, Hitachi, Tokyo, Japan; and strain-based elastography, Philips, Amsterdam, The Netherlands) or by the ARFI (VTI, Siemens HealthCare). For the 3 SW methods (VTQ, Siemens HealthCare; VTIQ, Siemens HealthCare; SSWE, SSI), the linear transducer was held still at the level of each target, avoiding any compression of the phantom. For each acquisition, the inclusion was centered in the field of view. The position of the transducer on the surface of the phantom was optimized manually, as it is recommended in clinical practice. For SE measurements, the operator used alternative compression and decompression pressure cycles using the visual scale when provided by the US system. For SWE measurements, the pressure applied on the surface of the phantom was kept as low as possible using a large amount of US gel, to avoid precompression of the phantom surface.

Each inclusion was imaged 10 times consecutively in 2 orthogonal planes to take into account any anisotropic effect of the phantom. For each acquisition, measurements were performed using a 5-mm ROI located at the center of each inclusion and in the background material. For background measurements, a 5-mm ROI was placed above (*front*), beneath (*back*), and on each side (*left* and *right*) at 5 mm from the inclusion side (Fig. 1). All measurements were performed within the first 3 cm below the surface of the phantom.

To review the features and principles for each elastography technique used in this study, see Table 1. Table 1 includes data collected for each method and