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● *Original Contribution*

POWER SPECTRUM CONSISTENCY AMONG SYSTEMS AND TRANSDUCERS

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Abstract—Use of the reference phantom method for computing acoustic attenuation and backscatter is widespread. However, clinical application of these methods has been limited by the need to acquire reference phantom data. We determined that the data acquired from 11 transducers of the same model and five clinical ultrasound systems of the same model produce equivalent estimates of reference phantom power spectra. We describe that the contribution to power spectral density variance among systems and transducers equals that from speckle variance with 59 uncorrelated echo signals. Thus, when the number of uncorrelated lines of data is small, speckle variance will dominate the power spectral density estimate variance introduced by different systems and transducers. These results suggest that, at least for this particular transducer and imaging system combination, one set of reference phantom calibration data is highly representative of the average among equivalent transducers and systems that are in good working order. (E-mail: tjhall@wisc.edu) © 2018 World Federation for Ultrasound in Medicine & Biology. All rights reserved.

Key Words: **Reference phantom method, Tissue characterization.**

INTRODUCTION

The reference phantom method (RPM) is a simple approach to computing quantitative ultrasound (QUS) backscatter parameters such as attenuation and backscatter coefficient (BSC) (Yao et al. 1990). The RPM has been used for more than 20 years in the laboratory and clinic (Hall et al. 1996; Nam et al. 2012, 2013) and has been reported to provide system-independent estimates of attenuation and the BSC (Nam et al. 2012). The list of potential clinical applications is long (Feleppa et al. 2004; Ghoshal et al. 2014; Gibson et al. 2009; Holland et al. 2004; Insana and Hall 1990; Insana et al. 1989; Lin et al. 2015; Mamou et al. 2011; McFarlin et al. 2015; Mottley et al. 1984; Yuan and Shung 1988). Clinical implementation of the RPM has been slow, hindered by the need to scan a well-calibrated reference phantom with the same clinical equipment and settings used to acquire data from the patient (Oelze and Mamou 2016).

In a recent review of QUS backscatter parameters, Oelze and Mamou (2016) suggested that it may be possible to eliminate the need for a physical reference phantom through "an extra step ... to collect data from reference phantoms and save it into the system so that it could readily be used for QUS calibration with the same system." The process of collecting reference phantom calibration data for a single transducer is non-trivial. One needs to ensure that the speed of sound of the reference phantom is close to that of the tissue (Nam et al. 2011) that system settings are consistent between tissue and reference phantom data acquisition (Yao et al. 1990).

Calibration of their own individual systems and transducers by users is clearly possible, but it would be immensely more efficient to have a set of reference power spectra loaded into the system by the manufacturer to be used for a specific combination of systems of a specific model, transducer and specific system configuration. A limited set of configurations could be defined—much as they are now for performing shear wave elasticity imaging.

In this article we compare the power spectra obtained from a commercial ultrasound phantom using a set of equivalent (same manufacturer and model number) ultrasound systems and transducers to

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determine the variability among them. The results illustrate that among this set of systems and transducers, there was minimal variability in power spectra. To explore the implications of using representative power spectra, we derived the theoretical variance of the attenuation and backscatter coefficient estimates taking into account components of variance among systems and transducers of the same model. We found that the relative contribution of system and transducer variance depended on the number of uncorrelated echo signals used in power spectral averaging and that, for typical clinical scanning conditions, components of power spectrum estimate variance from systems and transducers are negligible compared with the variance from echo signal variation caused by the underlying scattering stochastic process. These results suggest that an "average power spectrum" could be obtained from a small set of equivalent systems and transducers and that the average power spectrum could be used in reference phantom method calculations without the need to scan a reference phantom with each study, with negligible increase in QUS parameter estimate variance. The methods described here can be replicated with other systems and/or transducers to validate and extend the findings.

METHODS

This study was designed to determine whether variability in clinical ultrasound system or transducer performance was significant in power spectra estimated from a commercial ultrasound phantom. Power spectral estimation using pulse-echo ultrasound, under ideal conditions, is a sampling process whose distribution is determined by the number of independent acoustic A-lines used in power spectral estimation (Lizzi et al. 2006). The differential performance of systems and transducers is assumed to result in a distribution of power spectral estimates that may be modeled, to a first approximation, as a zero-mean normal distribution with unknown variance. The unknown variance represents the impact of small differences in manufacture of systems and transducers on their performance. Identifying the impact of system and transducer performance variability on power spectral estimate variability can be reduced to comparing the estimated distribution of power spectral estimates among systems and transducers with the distribution of power spectral estimates predicted by theory for the random scattering process.

Radiofrequency echo signal data acquisition

Eleven Siemens 6C1 curved linear array transducers (Siemens Medical Solutions USA, Inc., Malvern, PA, USA) and five Siemens Acuson S3000 systems (all running the same version of system software) were used to collect radiofrequency (RF) echo data from a Gammex Sono403 Multi-Purpose phantom (Gammex/RMI, Middleton, WI, USA). The Gammex Sono403 phantom consists of small (compared with the ultrasound wavelength) spherical scatterers (Madsen and Frank 1997) suspended in gelatin with "wire" and cylindrical targets at various intervals and depths. The phantoms have a specific attenuation of 0.5 dB/cm/MHz in the frequency range 2−18 MHz. A region in the background medium, well away from imaging targets in the phantom, was chosen to obtain "reference phantom data." The transducer and system serial numbers and approximate times in service are outlined in Table 1.

Transducers were secured in a holder attached to a translation stage. The apex of the curved transducer face was aligned perpendicularly to the phantom scanning window. Acoustic coupling was achieved using room temperature saline. RF echo signal data were collected using the Axius Direct Ultrasound Research Interface (Brunke et al. 2007). All RF echo signal data were sampled at 40 MHz. System and transducer settings were the same for all RF data acquisitions. The elevational focus of the 6C1 was at 6-cm depth. The transducer's electronic focus was set to 7 cm, and the transducer was excited with a single-cycle 2.5-MHz pulse.

Thirty frames of RF echo signal data were collected for each transducer or system tested. Each RF echo frame consisted of a curved-linear RF echo acquisition with 6323 axial time samples and 336 equally (angular) spaced A-lines with a depth of 12 cm. Care was taken, using the locations of the wire and cylindrical targets in the Gammex Sono403 phantom, to ensure that the RF echo data acquired for each transducer or system had

Table 1. Serial number and respective time in service for the transducers and imaging systems used in this study

Serial No.	Time in service (y)
6C1	
003E0102	—*
11500100	—
12000107	—
12000121	—
12400137	—
12500152	—
22290006	5
33430019	—
44138037	—
44541015	3
51613052	2
S3000	
200206	9
200215	8
200009	5
202558	4
211188	2

*Dashes represent transducers whose time in service was unknown.