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● *Original Contribution*

ATTENUATION COEFFICIENTS OF THE INDIVIDUAL COMPONENTS OF THE INTERNATIONAL ELECTROTECHNICAL COMMISSION AGAR TISSUE-MIMICKING MATERIAL

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Abstract—Tissue-mimicking materials (TMMs) are widely used in quality assurance (QA) phantoms to assess the performance of ultrasound scanners. The International Electrotechnical Commission (IEC) defines the acoustic parameters of up to 10 MHz. To manufacture a TMM that closely mimics the acoustical properties of small animal soft tissue at high frequencies, the acoustic properties of each of the individual component ingredients used in the IEC agar-TMM recipe need to be quantified. This study was aimed at evaluating whether the overall attenuation coefficient of the IEC agar-TMM is the linear sum of the attenuation coefficients of each of its ingredients. Eight batches of agar-based materials were manufactured with different combinations of ingredients from the IEC agar-TMM recipe. The percentage concentration of each ingredient used in the individual mixes was identical to that specified in the IEC recipe. The attenuation of each of these batches was measured over the ultrasound frequency range 12−50 MHz, and the attenuation value of the agar component was subtracted from the attenuation values of the other batches. Batch attenuation values, representing the attenuation of individual components within the IEC agar-TMM, were then summated and yielded attenuation values that accurately reproduced the attenuation of the IEC agar-TMM. This information forms a valuable resource for the future development of TMMs with acoustic properties similar to those of soft tissue at high frequencies. (E-mail: adela.rabell@ed.ac.uk) **© 2018 World Federation for Ultrasound in Medicine & Biology. All rights reserved.**

Key Words: **Tissue-mimicking material, Ultrasound, High frequency, Attenuation coefficient, Agar, Silicon carbide, Aluminium oxide.**

INTRODUCTION

Tissue-mimicking materials (TMMs) are widely used in quality assurance (QA) phantoms to assess the performance of ultrasound scanners. The International Electrotechnical Commission (IEC) provided a specification for the acoustic parameters for TMM (IEC 2001). The specifications of the acoustic parameters are defined for frequencies between 2 and 10 MHz and are 1540 ± 15 m/s for the speed of sound (SoS) and 0.5 ± 0.05 dB/cm/MHz for the attenuation coefficient. The IEC agar-based TMM has become widely used and has been acoustically characterised up to 60 MHz (Brewin et al. 2008; Rabell-Montiel et al. 2016, 2017; Rajagopal et al. 2014; Sun et al. 2012).

One approach used to manufacture a TMM that closely mimics the acoustical properties of small animal soft tissue at high frequencies (Rabell-Montiel et al. 2018) is to modify the properties of an existing, well-established TMM such as the IEC agar-TMM phantom. The first step in this process is to measure the acoustic properties of the individual component ingredients of the IEC agar-TMM recipe at high frequencies routinely used for pre-clinical imaging. Quantifying the acoustic properties of these individual components of the IEC agar-TMM will help to determine if it is possible to modify the existing TMM recipe to match the acoustical properties of small animal soft tissue at high ultrasonic frequencies. Additionally, the study of the individual components of IEC agar-TMM will test whether the overall attenuation of the IEC agar-TMM is the linear sum of the individual components and thus simplify the process of formulating a TMM with the appropriate attenuation properties.

Agar-based materials have been studied up to 14 MHz with changing agar concentrations up to 6.6%

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in weight (Gettings et al. 1977; Madsen et al. 2005; Manickam et al. 2014a, 2014b; Ross et al. 2006; Zell et al. 2007). The existing IEC agar-TMM recipe states that the agar component should be 3% of the total weight (Teirlinck et al. 1998). The acoustic properties of agar-based materials have been also measured by changing the concentrations (0−250%) of the three composition ingredients: glycerol, silicon carbide (SiC) and aluminium oxide (Al_2O_3). These measurements were performed using a scanning acoustic macroscope (SAM) system in the frequency range 14.8−24.5 MHz at 20˚C by Cannon et al. (2011). Furthermore, the attenuation of the agar-based material has also been assessed when increasing the percentage concentrations of both the 3- and 0.3-μm Al_2O_3 particles and SiC (400 grain) from 0 to 100% with the SAM system using a probe with a centre frequency of 7 MHz (Inglis et al. 2006). The results from these studies confirm that the attenuation of IEC agar-TMM increases with increasing frequency above 10 MHz (Brewin et al. 2008; Rabell-Montiel et al. 2016, 2017; Rajagopal et al. 2014; Sun et al. 2011, 2012). Furthermore, it is known that the attenuation coefficient and the backscatter of the IEC agar-TMM depends on the percentage concentrations of Al_2O_3 and SiC (Cannon et al. 2011; Inglis et al. 2006).

The aim of this study was to measure the attenuation of the individual components of the IEC agar-TMM to determine whether the overall attenuation of the IEC agar-TMM is the linear sum of the attenuations of its individual components. The acoustic properties of the ingredients of the IEC agar-TMM have not been studied previously at high frequencies.

METHODS

Manufacture of samples

Using a base of agar and glycerol in the same proportions as in the IEC agar-TMM recipe (Teirlinck et al. 1998), eight batches, each composed of 10 samples of agar-based TMM with varying constituent components, were manufactured (Table 1). The ingredients specified by the IEC for the TMM recipe are silicon carbide (SiC) and two particle sizes of aluminium oxide (0.3-μm Al_2O_3 and 3-μm Al_2O_3). The volumes of the ingredients used in the batches corresponded to those in the original recipe. For example, when making the B_{Al2O3} batch we omitted the 0.53% of SiC from the IEC agar-TMM recipe given in Table 2, but did not adjust any of the other weights of the components to account for the ingredient omitted. These samples were manufactured using a technique developed in previous experiments (Rabell Montiel et al. 2017) and briefly described here. Once the individual batches of agar-based TMM cooled to 42˚C, the mixture was poured into polyvinyl chloride rings (2 mm thick, 5.5-cm inner diameter) which had been previously located on a warm surface. After the TMM mixture was poured, a metal ruler was employed to wipe the excess of the TMM mixture using the upper surface of the polyvinyl chloride rings as a guide. The samples were then left to cool. The resultant thickness of the samples varied between 1.78 and 3.32 mm. Thin samples were needed because of

Table 1. Components of each of the TMM batches manufactured

Batch name	Ingredients	Agar	SiC	0.3-μm Al_2O_3	3-μm Al_2O_3
$B_{control}$	Control (IEC agar-TMM)	✓	✓	✓	✓
B_{SiC}	SiC	✓	✓		
B_{VWR}	Agar (VWR International Ltd.)	✓			
B_{Merck}	Agar (Merck Chemicals Ltd.)	✓			
$B_{SiC+0.3\mu Al_2O_3}$	SiC + 0.3-μm Al_2O_3	✓	✓	✓	
$B_{SiC+3\mu Al_2O_3}$	SiC + 3-μm Al_2O_3	✓	✓		✓
$B_{Al_2O_3}$	0.3-μm Al_2O_3 + 3-μm Al_2O_3	✓		✓	✓
$B_{0.3\mu Al_2O_3}$	0.3-μm Al_2O_3	✓		✓	
$B_{3\mu Al_2O_3}$	3-μm Al_2O_3	✓			✓

Table 2. Ingredients of agar-based tissue-mimicking material

Ingredient	Weight concentration	Manufacturer
Water	78.83%	
Glycerol 99% (pure)	11.21%	Sigma-Aldrich
Agar	3%	VWR International Ltd.
3-μm Al_2O_3 powder	0.95%	Logitech Ltd.
0.3-μm Al_2O_3 powder	0.88%	Logitech Ltd.
400-grain SiC power	0.53%	Logitech Ltd.
10% solution of benzalkonium chloride ($C_6H_5CH_2N(CH_3)_2RCl$)	4.6%	(50% solution, diluted in-house to 10%) Sigma-Aldrich