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● *Original Contribution*

ACOUSTIC PERFORMANCE OF MESH COMPRESSION PADDLES FOR A MULTIMODALITY BREAST IMAGING SYSTEM

Gerald L. LeCarpentier, Mitchell M. Goodsitt, Sacha Verweij, Jie Li, Frederic R. Padilla, and Paul L. Carson
Department of Radiology, University of Michigan Health Science System, University of Michigan, Ann Arbor, MI, USA

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Abstract—A system incorporating automated 3-D ultrasound and digital X-ray tomosynthesis is being developed for improved breast lesion detection and characterization. The goal of this work is to develop and test candidates for a dual-modality mesh compression paddle. A Computerized Imaging Reference Systems (Norfolk, VA, USA) ultrasound phantom with tilted low-contrast cylindrical objects was used. Polyester mesh fabrics (1- and 2-mm spacing), a high-density polyethylene filament grid (Dyneema, DSM Dyneema, Stanley, NC, USA) and a solid polymethylpentene (TPX; Mitsui Plastics, Inc., White Plains, NY) paddle were compared with no overlying structures using a GE Logic 9 (GE Healthcare, Waukesha, WI) with M12L transducer. A viscous gel provided coupling. The phantom was scanned 10 times over 9 cm for each configuration. Image volumes were analyzed for signal strength, contrast and contrast-to-noise ratio. X-ray tests confirmed X-ray transparency for all materials. By all measures, both mesh fabrics outperformed TPX and Dyneema, and there were essentially no differences between 2-mm mesh and unobstructed configurations. (E-mail: gllec@umich.edu or gllec@wayne.edu) © 2013 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Breast cancer screening, Automated ultrasound, Quality assessment.**

INTRODUCTION

Ultrasound imaging of the breast provides complementary information to conventional X-ray mammography. A primary example is the well-established use of ultrasound in differentiating solid masses from cysts. Another contribution of ultrasound in breast imaging is its utility in characterizing solid masses themselves. In fact, some studies using strictly enforced evaluation criteria indicate that current ultrasound technology may be a reliable means of identifying solid masses as benign or malignant and may be especially useful in detecting and diagnosing mammographically occult masses (Stavros et al. 1995). Despite these benefits, however, conventional ultrasound imaging is typically performed freehand in a geometry different from that of mammography. This may result in difficulties correlating areas of interest in the two image modalities (Conway et al. 1991). In addition, conventional breast ultrasound scanning is highly operator dependent and requires skillful probe manipulation and the mental ability of the operator to envision 3-D tissue structure (Shipley et al. 2005). Accurate diagnosis using breast sonography alone is also problematic, as indicated by numerous studies reporting high false-positive and false-negative rates (Berg 2003).

An X-ray/ultrasound mammography system can address these problems by combining a digital X-ray of the compressed breast with a subsequent 3-D ultrasound scan in the same orientation (breast compression being relaxed just enough for patient comfort). Such a system produces X-ray and ultrasound images in the same conventional mammographic imaging geometry (Booi et al. 2007; Kapur et al. 2002). These combined images could be helpful in the assessment of suspicious regions, given that simultaneous identification of multiple features suggestive of malignancy leads to higher diagnostic confidence (Stavros et al. 1995).

Kolb et al. (1998) reported that screening with both X-ray and ultrasound imaging modalities performed by a skilled physician using high-quality equipment provides a high correlation between ultrasound and X-ray mammography inexpensively and improves cancer detection significantly. Kolb has also expressed the belief (private communication) that the best approach to introducing successful ultrasound screening throughout the

Address correspondence to: Gerald L. LeCarpentier, UMHS Radiology Med Sci I Room 3226 A, 1301 Catherine Street, Ann Arbor, MI 48109–5667, USA. E-mail: gllec@umich.edu or gllec@wayne.edu

United States is through automated breast ultrasound (ABU) performed in the same compression as the mammogram or digital breast tomosynthesis (DBT).

Dual-mode whole-breast imaging also exhibits significant potential for advanced modes that can provide additional information about breast tissue not available using conventional mammography and ultrasound imaging. In particular, X-ray DBT could replace digital mammography in a combined system for 3-D co-delineation of tissue structures (Booi et al. 2007). Even fusion of conventional digital mammography images with co-registered ultrasound exams greatly reduces ambiguity in correlation of findings in the two exams. Initial results of such fusion of pulse echo ABU and of digital mammography or of DBT are promising, although there remain technical issues of breast coverage and some acoustic coupling artifacts in ABU (Kapur et al. 2004; Sinha et al. 2007).

One complication associated with performing ultrasound scans with the conventional polycarbonate compression paddle in a combined X-ray/ultrasound breast imaging system is the degradation of the ultrasound image volume resulting from the absorption and reflection of the ultrasound beam by the paddle. Additional challenges are: (i) the need to continuously stabilize the breast between the compression paddle and X-ray detector for both X-ray and ultrasound scans and (ii) the need to maximize breast coverage by the ultrasound imaging system. Thus, ease of use, as well as effective and time-economic acoustic coupling of the breast to the compression paddle and of the compression paddle to the ultrasound transducer, is essential. This double acoustic coupling requirement for a solid compression paddle is associated with a greater probability of coupling (*e.g.,* air bubble) artifacts than in hand-controlled contact scanning. Also, it is difficult to achieve adequate coupling at the breast periphery, where the breast curves away from the solid paddle. A promising alternative compression paddle is one made of mesh that is held taut within a thin rigid frame. If the mesh pores are sufficiently large, ultrasound gel can pass through the pores and provide acoustic coupling to the breast both where the mesh is in direct contact with the breast and where the mesh is several centimeters from the skin. Given that refraction artifacts at the gel/skin interface remain a concern, modeling of these effects and development of an appropriate coupling agent are currently under investigation in a separate study.

The mesh candidates for the dual-modality compression paddle that were considered in this study are thin enough and of low enough atomic number and density that they are not visible on the breast X-ray images (similar to Blane 2010); however, they do display different acoustic properties. Preliminary subjective studies, with polypropylene and polyester surgical mesh samples from Textile Developments Associates (Brookfield, CT, USA) have indicated that several polyester mesh materials are promising. with low acoustic attenuation and minimal artifacts. Other meshes tested, including most polypropylene and some polyester with different weave patterns, material thicknesses and pore sizes, exhibited significant attenuation and, in some cases, significant artifacts. The purpose of the study described here was to objectively quantify the acoustic effects of the promising polyester mesh samples as well as a paddle employing an ultrahigh-molecular-weight polyethylene fish line (Dyneema, DSM Dyneema Stanley, NC, USA) tightly strung across a frame, much like a tennis racket (Blane et al. 2010). Also included in the study was a solid polymethylpentene (TPX; Mitsui Plastics) plastic compression paddle that was employed in most of our initial dual-modality studies (Booi et al. 2007). The TPX material has the lowest density of any thermoplastic, giving it an ultrasonic impedance of 1.7 Rayleigh (R) and an attenuation of 5 dB/cm at 5 MHz. Because it is an entirely aliphatic polymer, its X-ray attenuation coefficient is also small.

METHODS

Experimental conditions

The effects of various mesh samples on ultrasound image quality were evaluated by imaging a Model 047 gray-scale contrast detail ultrasound phantom (Computerized Imaging Reference Systems [CIRS], Norfolk, VA, USA). This phantom is made of Zerdine (attenuation coefficient = 0.50 ± 0.05 dB/cm-MHz, sound speed = 1540 ± 10 m/s) and contains test cylinders 2.4, 4 and 6.4 mm in diameter, each tilted downward, as indicated in Figure 1. The objects of highest contrast were imaged over a broad range of depths, and the 4-mm-diameter cylinder with nominal anechoic contrast properties was used for the quantitative measures described below.

The test phantom was imaged at room temperature through a layer of ultrasound gel (Litho-Clear, Sonotech, Bellingham, WA, USA) to represent the "no compression paddle" or "no mesh" condition, and it was also imaged through the gel and various test layers representing different types of compression paddles These test layers included a "1-mm mesh" (Textile Developments Associates, Model PETKM3002, polyester, 1 mm × 0.9 mm pore size, 0.23 mm thick, 34 g/m^2) and a "2-mm mesh" (Textile Developments Associates, Model PETKM3003, polyester, 2.0 mm × 2.0 mm pore size, 0.15 mm thick, 14 g/m^2). In addition, the 1-mm mesh was placed on top of a second 1-mm mesh for improved gel containment; the 2-mm mesh was placed on top of a 1-mm mesh for improved gel containment; and a 3-mm-spaced Dyneema (~0.18 mm diameter) fish-line weaved mesh