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● *Technical Note*

COMPARISON OF TWO INEXPENSIVE RAPID PROTOTYPING METHODS FOR MANUFACTURING FILAMENT TARGET ULTRASOUND PHANTOMS

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Abstract—Current use of 3-D printers to manufacture ultrasound phantoms is limited to relatively expensive photopolymer jetting printers. The present work investigates the feasibility of using two common and inexpensive 3-D printer technologies, fused deposition modeling (FDM) and digital light processing (DLP), to print custom filament target phantoms. Acoustic characteristics obtained from printed solid blocks indicated that the printing materials—acrylonitrile butadiene styrene and polylactic acid for FDM and a photopolymer for DLP printing—were appropriate for use as scatterers. A regular grid of filaments was printed to study printing accuracy. As a proof of concept of the phantom manufacturing process, a complex pattern of filament targets was placed in de-ionized water to create a phantom, which was then imaged using an ultrasound imager. The pattern was clearly identifiable, although multiple reflections were observed, which underscores the importance of future work to enhance printing resolution. This goal is deemed possible using improvement of the DLP printing setup. (E-mail: fuzesi.krisztian@itk.ppke.hu) © 2016 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Ultrasound phantom, Filament targets, Filaments, 3-D printing.**

INTRODUCTION

Ultrasound phantoms are widely used for quality assurance (QA) testing of ultrasound imaging systems and validation of novel imaging methods, as well as the simulation of tissue images for training purposes (Boote 2014). A wide variety of well-established phantom materials and manufacture methods exist, both commercial and in-house (Browne et al. 2003; Culjat et al. 2010). One common need arising in phantom manufacture is the introduction of spatial structure into the phantom at various geometric scales. For instance, different concentrations of micrometer-scale scatterers are often added to achieve regions with different levels of hyperechogenicity, and the regions themselves can be separated from each other using molds (Boote 2014; Culjat et al. 2010). As another example, wires or string can be used to simulate vasculature (Chmarra et al. 2013). Filaments are also used to measure axial and transverse image resolution as part of QA testing (American College of Radiology [ACR] 2016; Goodsitt et al. 1998; Kollmann et al. 2012; Moran et al. 2008), although their ability to relate these measures to clinical performance appears to be limited (Shaw and Hekkenberg 2007). This is in part due to the difficulty of relating resolution in the three dimensions to overall resolution and a frequency dependence of backscatter that differs from that of tissue (Rowland et al. 2009). As a result, alternative methods based on other inclusions, such as anechoic cylinders (Pye and Ellis 2011; Pye et al. 2004), anechoic spheres (Filoux et al. 2011) or step targets (Rowland et al. 2009), are being explored.

All of the phantoms described above are made using conventional manufacturing techniques that are unable to place a large number of discrete scatterers at exactly specified locations. Such an ability could enhance the realism of conventional tissue-mimicking phantoms, as well as allow experimental validation of imaging techniques such as adaptive beamforming that seek to separate otherwise unresolved scatterers (Li and Stoica 2005; Nilsen and Hafizovic 2009; Sakhaei 2015).

One possible solution to the bespoke placement of discrete scatterers comes from recent advances in 3-D printing technology. Three-dimensional printed materials are typically harder than soft tissue, finding wide use as a bone-mimicking material (An et al. 2015; Gatto et al. 2012; Shirazi et al. 2015; West et al. 2014). Although a

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plethora of 3-D printing materials are available, it is difficult to find one whose acoustic properties (in particular, speed of sound and attenuation) closely match those of soft tissue. Recently, several groups have used a material (FullCure 705, Stratasys, Eden Prairie, MN, USA) with unpolymerizable components as the propagation medium to manufacture ultrasound phantoms using photopolymer jetting technology (Cloonan et al. 2014; Jacquet et al. 2015). Photopolymer jetting printers, however, are relatively expensive, typically costing more than $25,000. Moreover, the speed of sound of FullCure705, 1617 m/s, is somewhat above the typical value of 1540 m/s assumed for soft tissue. The current work describes the use of a fused deposition modeling (FDM) 3-D printer and a custom-made 3-D printer using a digital light processing (DLP) projector to create inexpensive filament target phantoms. The space between the filaments can be filled with any material used in conventional phantom manufacture technology to produce the desired speed of sound and attenuation. In the current work, water was used as the propagation medium. The aim of the current work was to compare the feasibility of using FDM and DLP to create filament target phantoms, with a particular focus on the acoustic characteristics of the printing materials, the dimensions of the filaments and their appearance on ultrasound images.

The structure of the remainder of the article is as follows. First, the use of FDM and DLP printing is described under Printing Methods. Next, the methods of characterizing the printed materials, the filament structures and the resulting filament phantoms thereby obtained are described. This is followed by a presentation and discussion of the characterization results. Last, the results are summarized, with a view toward identifying future refinements and possibilities.

PRINTING METHODS

Fused deposition modeling printing

In FDM printing, a filament is passed through a heated nozzle that extrudes the molten material (Fig. 1). The nozzle is moved in the x–y direction to form a layer of the material. When a layer is completed, the stage is moved in the z direction to allow the next layer to be constructed.

In the current work, a commercially available FDM printer (Flashforge Dreamer, Flashforge, Jinhua, China) accepting the commonly used STL file format was used with two commonly available 1.75-mm-diameter round filaments: acrylonitrile butadiene styrene (ABS) and polylactic acid (PLA), both manufactured by MakerBot (New York, NY, USA). A thermoplastic polyurethane (TPU) material was also tested (Filaflex, Recreus, Elda, Spain), although, as will be seen in the next section, the testing went only as far as the material characterization phase. Paper glue on masking tape was used to fix the first layer of printing on the platform. Printing parameters, according to manufacturer recommendations, are summarized in Table 1. Objects were designed in AutoCAD 2015 (Autodesk, San Rafael, CA, USA) and then exported to STL format for printing. When generating

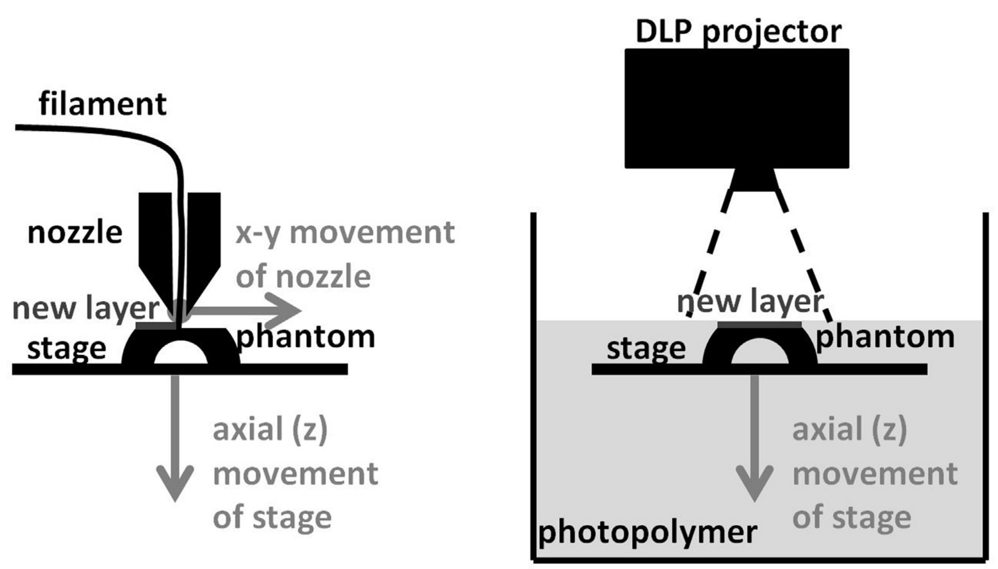

Fig. 1. Schematics of the printing techniques employed in the current work. Left: Fused deposition modeling (FDM) printing. By moving a heated nozzle in the x–y plane (one of the directions is out of the plane), a layer of molten material can be deposited. Movement of the stage in the z direction achieves 3-D printing. Right: Digital light processing (DLP) printing. Similarly to the FDM technique, the phantom is manufactured layer by layer using a mechanical stage. However, in this case, each layer is formed simultaneously by projection of an image onto the surface of a liquid photopolymer. The photopolymer cures on exposure to the UV radiation emitted by the DLP projector.