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● *Original Contribution*

EVALUATION OF EXAMINER PERFORMANCE USING A DUPLEX ULTRASOUND SIMULATOR. FLOW VELOCITY MEASUREMENTS IN DIALYSIS ACCESS FISTULA MODELS

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Abstract—We developed a duplex ultrasound simulator for training and assessment of scanning skills. We used the simulator to test examiner performance in the measurement of flow velocities in dialysis access fistulas. Test cases were created from 3-D ultrasound scans of two dialysis access fistulas by reconstructing 3-D blood vessel models and simulating blood flow velocity fields within the lumens. The simulator displays a 2-D B-mode or color Doppler image corresponding to transducer position on a mannequin; a spectral waveform is generated according to Doppler sample volume location and system settings. Examiner performance was assessed by comparing the measured peak systolic velocity (PSV) with the true PSV provided by the computational flow model. The PSV measured by four expert examiners deviated from the true value by 7.8 ± 6.1%. The results indicate the ability of the simulator to objectively assess an examiner's measurement accuracy in complex vascular targets. (E-mail: eotta@uw.edu) **© 2018 World Federation for Ultrasound in Medicine & Biology. All rights reserved.**

Key Words: **Duplex ultrasound, Medical simulation, Dialysis access fistula, Color Doppler, Doppler spectral waveform, Peak systolic velocity.**

INTRODUCTION

Simulation for training in ultrasound provides such advantages as immediate availability of a wide range of clinical scenarios or pathology and avoidance of patient comfort and safety concerns associated with having trainees perform clinical examinations. Medical ultrasound simulators have been developed for a variety of diagnostic and point-of-care applications, including echocardiography, obstetrics, trauma and critical care (Ferrero et al. 2014; Liu et al. 2015; Paddock et al. 2015; Parks et al. 2013). These simulators, however, focus on 2-D B-mode images, whereas vascular ultrasound examinations rely primarily on Doppler assessment of blood velocities and flow patterns. In duplex ultrasound scanning, blood flow is characterized by Doppler spectral waveforms and color Doppler imaging (Beach et al. 2010). The peak systolic velocity (PSV) obtained from the Doppler spectral waveform is the principal criterion for the classification of arterial stenosis (Beach et al. 2012). A simulator for training and assessment in vascular ultrasound examinations requires realistic representations of the color Doppler images and Doppler spectral waveforms that must be acquired during performance of a complete duplex scan.

We have developed a computer-based duplex ultrasound simulator that incorporates real-time color Doppler images and Doppler spectral waveforms along with corresponding B-mode images. Testing results with the simulator for normal and stenotic carotid artery models have previously been reported (Zierler et al. 2016). Here we describe testing results for more complex vascular models: dialysis access fistula cases that include flow simulations for the arterial inflow, the arterial–venous anastomosis and the venous return.

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Conflict of interest disclosure: Dr. Sheehan is the founder and President of Sheehan Medical, LLC, which markets a transthoracic echocardiography (TTE) simulator that she and co-investigators developed and validated at the University of Washington (UW). Dr. Sheehan supports research in medical education by lending TTE simulators from her laboratory at the UW to investigators for up to 6 mo. Neither the co-authors of this article, nor the UW is involved in Sheehan Medical, LLC, and none receives any benefit from simulator sales.

Hemodialysis treatments for patients with end-stage renal failure (ESRD) require cannula access to blood flow at two sites along a vessel segment, one for withdrawing blood and the other for returning it to the patient. A dialysis access fistula is a surgical connection between an artery and a vein that produces higher than normal blood flow through the venous return segment. This segment can then be cannulated to supply the high-flow-volume flow rates required for effective hemodialysis. Flow rates through a dialysis access fistula are of clinical importance because these fistulas are susceptible to stenosis development, which can reduce blood flow and eventually compromise the dialysis procedure (Kohler and Mraz 2015). Doppler ultrasound examination of dialysis access fistulas can be challenging because of the non-standard anatomy produced by the surgical connection of an artery and a vein, the unique and often complex vascular configuration at the arterial–venous anastomosis and flow velocities that can be significantly higher than those observed in normal blood vessels (Teodorescu et al. 2012).

METHODS

Doppler simulator design

The duplex ultrasound simulator hardware (Fig. 1) consists of a personal computer, a mannequin and a mock transducer whose spatial location and orientation are measured using a tracking device (Patriot, Polhemus Inc., Colchester, VT, USA). As the examiner manipulates the mock transducer over the mannequin, the computer displays ultrasound images in a 2-D B-mode view that changes in real time according to the transducer's position and orientation. These images are extracted in real time from a 3-D volume of image data previously generated from scans of patients or normal volunteers (Sheehan et al. 2013). In addition, computational flow modeling is used to populate a 3-D computer model of the blood vessel with time-varying velocity vectors that define the blood flow at all points within the vessel (McGah et al. 2011, 2012, 2013). This velocity field is sampled along with the image data to create a spectral waveform display that responds in real time to the control panel settings selected by the examiner. The steps from 3-D ultrasound scanning to simulated spectral waveform display are described in the following sections.

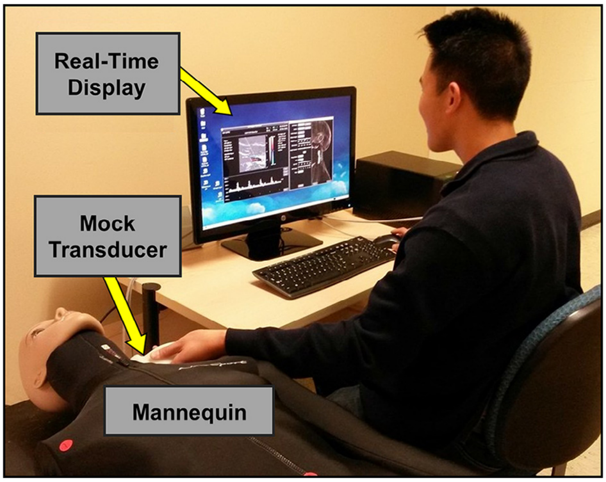

Fig. 1. Photograph of the Doppler ultrasound simulator system. A spatial tracking system records the position and orientation of the mock transducer in real time; a magnetic field transmitter is located inside the mannequin and a receiver is fixed inside the plastic transducer housing. As the examiner moves the mock transducer over the mannequin, a 2-D B-mode image derived from a saved 3-D data set is displayed. A Doppler spectral waveform display is generated in real time from the velocity database as the examiner positions the Doppler sample volume and adjusts the control panel settings.

Patient scanning and 3-D image reconstruction

Three-dimensional ultrasound scans were performed on two patients with dialysis access fistulas. The imaging procedure was approved by the University of Washington institutional review board, and the patients gave informed consent. Case 1 was a mature and normally functioning end-to-side fistula in the lower arm near the wrist. Case 2 was a recent (10 mo post-surgery) end-to-side fistula in the lower arm near the elbow, with a narrowed region in the venous return segment. End-to-side fistulas are created by surgically transecting the vein, attaching the proximal end to the side of the artery and tying off the distal end of the vein.

The 3-D ultrasound data sets included gray-scale (B-mode) images of the dialysis access proximal inflow artery, arterial–venous anastomosis, distal artery and proximal return vein. An ultrasound transducer with an attached tracking device (Flock of Birds, Ascension Technology Corp., Burlington, VT, USA) was used to acquire closely spaced B-mode images along the length of the vessels of interest (Leotta and Martin 2000a, 2000b) (Fig. 2a). Custom software developed using the LabVIEW engineering software package (National Instruments, Austin, TX, USA) was used to synchronously capture 2-D ultrasound images and 3-D tracking data at the rate of 30 frames/s. For each dialysis access case, 900 images were captured during a 30-s continuous scan along the length of the target vessels. These images were re-formatted into a regular 3-D grid using a volume reconstruction algorithm (Leotta and Martin 2000a, 2000b) (Fig. 2b). A 3-D surface model of the blood vessel was then generated from traced borders of the vessel lumens in parallel planes extracted from the reconstructed volume data sets (Leotta et al. 2001a, 2001b) (Fig. 2c).

Calculation of blood flow velocity

Computational fluid dynamics (CFD) modeling was applied to the 3-D vessel surface models to calculate 4-D flow velocity fields (spatially 3-D and temporally resolved) inside the vascular lumen (McGah et al. 2011, 2012,