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● *Original Contribution*

VECTOR AND DOPPLER ULTRASOUND VELOCITIES EVALUATED IN A FLOW PHANTOM AND THE FEMOROPOPLITEAL VEIN

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Abstract—Ultrasound is used for evaluating the veins of the lower extremities. Operator and angle dependency limit spectral Doppler ultrasound (SDUS). The aim of the study was to compare peak velocity measurements in a flow phantom and the femoropopliteal vein of 20 volunteers with the angle-independent vector velocity technique vector flow imaging (VFI) and SDUS. In the flow phantom, VFI underestimated velocity ($p = 0.01$), with a lower accuracy of 5.5% ($p = 0.01$) and with no difference in precision, that is, error factor, compared with SDUS (VFI: 1.02 vs. SDUS: 1.02, $p = 0.58$). *In vivo*, VFI estimated lower velocities (femoral: $p = 0.001$; popliteal: $p = 0.001$) with no difference in precision compared with SDUS (femoral: VFI 1.09 vs. SDUS 1.14, $p = 0.37$; popliteal: VFI 1.13 vs. SDUS 1.06, $p = 0.09$). In conclusion, the precise VFI technique can be used to characterize venous hemodynamics of the lower extremities despite its underestimation of velocities. (E-mail: thorbechsgaard@gmail.com) © 2017 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Ultrasound, Spectral Doppler, Peak velocity, Flow phantom, Popliteal vein, Femoral vein, Vector flow imaging.**

INTRODUCTION

A quarter of the world's population suffers from venous disease (Michaels et al. 2006), and ultrasound (US) is the backbone in diagnosing acute as well as chronic venous disorders of the lower extremities (Needleman 2014; Wittens et al. 2015). Doppler US—that is, color Doppler US and spectral Doppler US (SDUS)—is used to characterize hemodynamic changes in patients before further imaging and treatment. With color Doppler US, blood flow is evaluated qualitatively, whereas SDUS is used for pulse wave analyses and peak blood flow velocity measurements (Wood et al. 2010). US does not expose patients to radiation, and it is inexpensive and non-invasive unlike other medical imaging techniques, for example, computed tomography, magnetic resonance imaging, intravenous phlebography and intravascular US (Arnoldussen et al. 2013). However, color Doppler US and SDUS are limited by angle dependency and high observer variability, which affect velocity estimates and complicate evaluation of vein segments running parallel to the surface of the skin, for example, the femoral vein (Labropoulos et al. 2007; Lui et al. 2005; Ricci et al. 2015; Tortoli et al. 2015). Despite the limitations, color Doppler US and SDUS are used in combination with a clinical examination to decide the need for further imaging investigations and potential treatment (Metzger et al. 2016; Wittens et al. 2015).

The angle dependency of conventional velocity estimation with SDUS has been addressed previously, and efforts have been made to create an angle-independent vector velocity US system capable of

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measuring vector flow (Fox 1978; Newhouse et al. 1987; Overbeck et al. 1992, Trahey et al. 1987). The transverse oscillation vector flow imaging (VFI) method estimates the vector velocity angle independently (Jensen and Munk 1998), and several studies have been published on the subject (Brandt et al. 2016; Hansen et al. 2013, 2014, 2015a; Pedersen et al. 2012). However, there is only one preliminary study with VFI on venous flow in the popliteal vein, which reported that compared with SDUS, VFI measured a lower peak velocity, but with improved precision (Bechsgaard et al. 2016).

The objective of this study was to compare the precision of peak velocity magnitude estimation in the femoropopliteal vein in a young, healthy study population obtained with VFI and SDUS. Furthermore, in a flow phantom, the accuracy and precision of VFI estimations at flow angles between 60° and 90° were compared with those of corresponding SDUS estimations.

METHODS

Vector flow imaging

The transverse oscillation VFI method was introduced in 1998 and is an angle-independent method for estimation of blood flow (Jensen and Munk 1998). The velocity components of the blood are estimated in the axial as well as the transverse direction. The axial velocity component is found as in conventional velocity estimation, whereas the transverse velocity component is found by changing the apodization of the receiving elements and using a special estimator (Jensen 2001). VFI visualizes blood flow in a color box as in color Doppler US, with arrows superimposed on the vector map to indicate flow direction and magnitude (Fig. 1).

US equipment and data processing

Spectral Doppler US and VFI measurements were obtained on a commercial US scanner (BK3000, BK Ultrasound, Herlev, Denmark) with a linear transducer (10 L2 w Wide Linear, BK Ultrasound) for both the phantom and the *in vivo* study. VFI peak velocities were recorded with AVI files consisting of 110 vector velocity maps corresponding to 5 s of data acquisition. The corresponding SDUS peak velocities were recorded with screenshots that visualized spectrograms of 5-s duration and evaluated offline using a professional quality vector graphics editor (Inkscape, C/O Software Freedom Conservancy, Brooklyn, NY, USA).

The AVI files for VFI estimations and screenshots for SDUS estimations captured approximately 5 s of constant flow for the phantom measurements and a single venous pulse wave for the *in vivo* measurements. The VFI estimates were displayed in real time on the scanner, but the quantification of the peak velocities required offline processing with an in-house developed script for MATLAB (The MathWorks, Natick, MA, USA), as previously described (Hansen et al. 2014; Pedersen et al. 2012). In the images, that is, AVI files extracted from the US scanner, each pixel was color encoded according to the axial and transverse vector velocity magnitudes. These images were used as input to the estimator. A region of interest of 1 × 1 cm was manually chosen from within the vessel boundaries, and the peak velocity magnitude was found from a 2-D vector field within this region.

Phantom setup

A flow phantom (Cole-Parmer centrifugal pump, Vernon Hills, IL, USA) recirculated a blood-mimicking fluid (BMF-US, Shelley Medical Imaging Technologies, Toronto, ON, Canada) with a controlled velocity of 60.3 cm/s (MAG1100, Danfoss, Nordborg, Denmark). The transducer was fixated at 5 cm from a 12-mm-diameter vessel and examined with VFI at beam-to-flow angles of 90°, 80°, 70° and 60°. With SDUS, the transducer was in the same position as the corresponding VFI measurements, but electronic angle correction of 30° changed the beam-to-flow angles to 60°, 50°, 40° and 30°. With both techniques, 10 repeated measurements were recorded at each of the four different angle positions. VFI pulse repetition frequency was set at 7 kHz, and SDUS pulse repetition frequency at 4 kHz. The smoothing filter, persistence, wall filter and c-gain were set identically with the two techniques. The size and location of the color box and the depth of the B-mode image were kept constant through all measurements. The SDUS and VFI recordings were blinded during the data acquisition.

Volunteers

Twenty healthy volunteers (Table 1), 10 men and 10 women, participated and were evaluated with SDUS and VFI (Fig. 1). The study was approved by the Danish National Committee on Biomedical Research Ethics and the local ethics committee (H-1-2014-FSP-072), as well as by the Danish Data Protection Agency (2012-58-0004). All volunteers were included in the study after submitting informed consent.

Controlled scan setup

The set-up previously described by Bechsgaard et al. (2016) was used. A cuff compression–decompression system was applied to the lower leg of a standing volunteer according to a setup described by van Bemmelen et al. (1989) and replicated by others to ensure a standardized pulse wave in the veins (Konoeda et al. 2014) (Fig. 2). For each volunteer, the right popliteal vein and the right femoral vein in the midthigh region were scanned longitudinally. To avoid manual compression, the transducer was not tilted during examination, as