Ultrasound in Med. & Biol., Vol. 00, No. 00, pp. 1−10, 2018

0301-5629/$ - see front matter

ELSEVIER

https://doi.org/10.1016/j.ultrasmedbio.2018.05.006

● *Original Contribution*

RESPIRATORY VARIABILITY OF PEAK VELOCITIES IN THE COMMON FEMORAL VEIN ESTIMATED WITH VECTOR FLOW IMAGING AND DOPPLER ULTRASOUND

Thor Bechsgaard,* Kristoffer Lindskov Hansen,* Andreas Hjelm Brandt,* Ramin Moshavegh,† Julie Lyng Forman,‡ Pia Føgh,§ Lotte Klitfod,§ Niels Bækgaard,§ Lars Lönn,* Michael Bachmann Nielsen,* and Jørgen Arendt Jensen†

* Department of Diagnostic Radiology, Rigshospitalet − Copenhagen University Hospital, Copenhagen Ø, Denmark; † Center for Fast Ultrasound Imaging, Department of Electrical Engineering, Technical University of Denmark, Lyngby, Denmark; ‡ Section of Biostatistics, Department of Public Health, Copenhagen University, Copenhagen K, Denmark; and § Department of Vascular Surgery, Rigshospitalet & Gentofte Hospital − Copenhagen University Hospital, Hellerup, Denmark

(*Received* 14 *November* 2017; *revised* 26 *April* 2018; *in final from* 4 *May* 2018)

Abstract—Respiratory variability of peak velocities (RVPV) in the common femoral vein measured with ultrasound can reveal venous outflow obstruction. Pulse wave (PW) Doppler is the gold standard for venous velocity estimation of the lower extremities. PW Doppler measurements are angle dependent, whereas vector flow imaging (VFI) can yield angle-independent measures. The hypothesis of the present study was that VFI can provide RVPV estimations without the angle dependency of PW Doppler for an improved venous disease assessment. Sixty-seven patients with symptomatic chronic venous disease were included in the study. On average, VFI measured a lower RVPV than PW Doppler (VFI: 14.11 cm/s; PW: 17.32 cm/s, $p = 0.002$) with a non-significant improved precision compared with PW Doppler (VFI: 21.09%; PW: 26.49%, $p = 0.08$). In a flow phantom, VFI had improved accuracy ($p < 0.01$) and equal precision compared with PW Doppler. The study indicated that VFI can characterize the hemodynamic fluctuations in the common femoral vein. (E-mail: thorbechsgaard@gmail.com)

Key Words: **Ultrasonography, Doppler ultrasonography, Pulse wave Doppler, Beam steering, Common femoral vein, Respiratory variability of peak velocities, Chronic venous disease, Vector flow imaging.**

INTRODUCTION

Pulse wave (PW) Doppler ultrasound (US), a non-invasive and cost-effective technique, is the current standard test for evaluation of varicose veins and lower extremity deep venous thrombosis (Hamper et al. 2007). Venous outflow obstruction involves the iliac veins, and can be caused by chronic changes after deep venous thrombosis, extrinsic compression, or intrinsic narrowing (Eberhardt and Raffetto 2014; Lin et al. 2007). PW Doppler can discriminate venous outflow obstruction both directly and indirectly (Khilnani 2014). Directly, gradients are estimated across the narrow segments of the iliac veins (Labropoulos et al. 2007), and indirectly, the respiratory variability of peak velocities (RVPV) is determined in the common femoral veins (Lin et al. 2007). The superficial location of the common femoral vein eases the indirect examination and is considered a routine examination of the lower extremity veins (Hamper et al. 2007). The direct examination of iliac veins is considered an expert task due to the challenging deep location in the pelvis (Arnoldussen et al. 2013; Metzger et al. 2016).

The angle-dependent PW Doppler technique is cumbersome when examining blood vessels (*e.g.*, the common femoral vein) with a course near and parallel to the surface of the skin as manual angle correction and electronic beam steering are limited (Lui et al. 2005; Park et al. 2012; Steinman et al. 2005). Transverse oscillation vector flow imaging (VFI) introduced by Jensen and Munk (1998) is less limited by insonation angle than

Address Correspondence to: Thor Bechsgaard, Department of Radiology, Rigshospitalet, Blegdamsvej 9, 2100 Copenhagen Ø, Denmark. E-mail: thorbechsgaard@gmail.com

Danish National Advanced Technology Foundation and BK Ultrasound. The author JAJ developed and patented the Transverse Oscillation technique and earns royalties from the sale of scanners with the Transverse Oscillation Vector Flow Imaging technique implemented from BK Ultrasound.

PW Doppler and can therefore be categorized as an angle-independent technique. Several papers have confirmed the usability of the technique in various vessel geometries (Hansen et al. 2017a; Hansen et al. 2014; Pedersen et al. 2012), but VFI has not yet been applied on patients with symptomatic chronic venous disease.

Several other VFI techniques have previously been suggested. Dunmire et al. (2000) summarized the extensive work with crossbeam vector Doppler US, whereas Jensen et al. (2016a, 2016b) summed up the different technical approaches to achieve VFI. Hansen et al. (2017b) reviewed various clinical and pre-clinical applications of different VFI techniques, and Au et al. (2018) looked at different plane wave techniques. Previous studies have focused on measurements in flow phantoms, the heart, and the carotid arteries (Ekroll et al. 2014; Fadnes et al. 2014; Goddi et al. 2017a; Ishii et al. 2017; Møller Pedersen et al. 2014; Tortoli et al. 2010; Tortoli et al. 2015; Wang et al. 2016; Yiu et al. 2014). Vector velocity estimation of flow in dialysis fistula, the portal vein, the aorta, and veins of the lower extremities also has been examined (Bechsgaard et al. 2017; Brandt et al. 2017; Fiorina et al. 2017; Hansen et al. 2016; Hansen et al. 2014). Various manufacturers offer US systems with vector flow modalities; however, flow quantification given directly on the scanner has not yet been achieved. The advantages of the new flow tool include visualization and quantification of complex flow, new insonation windows, and reduction of operator dependency. The intuitive visualization of blood flow and the straightforward velocity estimation with VFI could reduce examination time and improve work flow (Goddi et al. 2017b; Hansen et al. 2017c).

The aim of this study was to compare VFI and PW Doppler estimates of RVPV in common femoral veins of patients with symptomatic chronic venous disease. The hypothesis of the study was that VFI can replace PW Doppler for RVPV estimation to improve venous disease assessment.

Additionally, flow phantom measurements of both methods were performed in a controlled setting to evaluate the accuracy and precision *in vitro*. The flow phantom measurements were included to evaluate the accuracy of both methods in lack of a solid *in vivo* ground truth, *e.g.,* phase-contrast magnetic resonance angiography (MRA; Jiang et al. 2011).

MATERIALS AND METHODS

Vector flow imaging

The angle-independent vector velocity technique VFI use conventional Doppler US emissions, but with a changed sensitivity of the transducer array in receive combined with a special estimator to determine vector velocity (Jensen 2001; Jensen and Munk 1998). VFI produces a two-dimensional (2-D) vector map with superimposed vector arrows to show flow, which is velocity magnitude and direction of the moving blood (Fig. 1). The method is implemented on the BK3000 US scanner, and the quantitative velocity estimates can be stored for later processing.

Phantom setup

A blood-mimicking fluid (BMF-US; Shelley Medical Imaging Technologies, Toronto, ON, Canada) was examined at controlled constant flow velocities (MAG3000, Danfoss, Nordborg, Denmark) of 10, 20, 30 and 40 cm/s in a flow phantom (Cole-Parmer centrifugal pump, Vernon Hills, IL, USA). Both techniques were examined with the transducer fixated 20 mm from a 12 mm-diameter tubing containing the circulating fluid. The transducer array and the tube were placed parallel to each other. Ten repeated measurements were recorded with VFI and PW Doppler at the four different velocities. Settings were optimized and kept constant during the recordings for the two techniques to simulate the conditions found *in vivo*. The insonation angle was kept constant at 90 degrees for VFI and at 60 degrees for PW Doppler, respectively. For PW Doppler, the US beam was 30 degrees steered, and thereby, the insonation angle was reduced to 60 degrees as suggested by others (Park et al. 2012; Quirk and Bandyk 2013), whereas the insonation angle for VFI was set to 90 degrees. The reference velocity in the flow phantom was obtained by a calibrated magnetic flow meter (MAG3000, Danfoss, Nordborg, Denmark). The flow meter measured mass flow with an accuracy of 1% according to the data sheet of the manufacturers, and the exact velocity values can be calculated from this.

Patients

The study was approved by the Danish National Committee on Biomedical Research Ethics and the local ethics committee (H-15007065) as well as by the Danish Data Protection Agency (2012-58-0004). Patients were recruited from a tertiary venous center from the waiting list on intravenous intervention of superficial veins of the lower extremities. Sixty-seven patients were prospectively included from August 11, 2016 to January 31, 2017 (Table 1). All patients were examined with US by a vascular surgeon before inclusion, and all patients had normal morphology and respiratory variation in the iliac veins. None of the included patients in this study were diagnosed with venous outflow obstruction. In the present study, $\geq$90% of the patients suffered from chronic venous disease presenting solely with varicose veins, whereas only a minority of the patients had signs of advanced chronic venous disease, which is chronic