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● *Original Contribution*

JUGULAR VENOUS FLOW QUANTIFICATION USING DOPPLER SONOGRAPHY

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Abstract—A consensus on venous flow quantification using echo spectral Doppler sonography is lacking. Doppler sonography data from 83 healthy individuals were examined using manually traced transverse cross-sectional area and diameter-derived cross-sectional area obtained in longitudinal view measurements of the internal jugular vein. Time-averaged velocity over a 4-s interval was obtained in the longitudinal plane using manual tracing of the waveform. Manual and computer-generated blood flow volume calculations were also obtained for the common carotid artery, for accuracy purposes. No differences were detected between semi-automated and manual blood flow volume calculations for the common carotid artery. The manual calculation method resulted in almost twofold larger venous internal jugular vein flow measurements compared with the semi-automated method. Doppler sonography equipment does not provide accurate automated calculation of venous size and blood flow. Until further technological development occurs, manual calculation of venous blood flow is warranted. (E-mail: rzivadinov@bnac.net) © 2018 World Federation for Ultrasound in Medicine & Biology. All rights reserved.

Key Words: **Doppler sonography, Internal jugular vein, Blood flow, Veins.**

INTRODUCTION

Doppler sonography (DS) is the imaging technique most frequently utilized to evaluate the vascular system. The hemodynamic evaluations derived from the ultrasonography method are critical for correct diagnosis of emergency, cardiac, obstetric, hepatic and neurologic conditions (Ficial et al. 2013; Naqvi et al. 2013; Stankovic et al. 2012). For example, measurement of respiratory changes at the level of the inferior vena cava is highly associated with invasively determined central venous pressure (Nagdev et al. 2010). Nagdev et al. proposed that DS-derived respiratory changes of the inferior vena cava were ≥50% correlated with an invasively derived central venous pressure <8 mm Hg (Nagdev et al. 2010). Similarly, measurements of changes in internal jugular vein (IJV) cross-sectional area (CSA) during the cardiac cycle can be used to estimate the jugular venous pulse (Sisini et al. 2015). Despite potential inaccuracies, DS observation of IJV pulsatility remains an acceptable method of central venous pressure monitoring (Constant 2000).

Spectral DS analysis of IJVs or vertebral veins is an emerging concept in examining their physiologic hemodynamic ranges. Recent vascular studies indicate abnormal extracranial venous flow in a variety of central nervous system disorders, such as Meniere syndrome (Di Berardino et al. 2015), migraine (Chung et al. 2010), transient global amnesia (Cejas et al. 2010), multiple sclerosis (Zivadinov et al. 2011), Parkinson's disease (Liu et al. 2015), obstructive sleep apnea (Chi et al. 2015) and cough headache (Chuang and Hu 2005), among others. Therefore, an accurate and reproducible DS method for calculating venous blood flow volume (BFV) is needed. Although extracranial venography is the imaging gold standard for detecting venous abnormalities in the neck, DS provides a portable, cost-efficient, non-invasive assessment of the neck veins, potentially allowing screening in larger numbers of patients (Zivadinov et al. 2014).

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Table 1. Review of methods used for measurement of cross-sectional area and velocity of the internal jugular vein

Reference	CSA measurement	Velocity measurement
Sisini et al. (2015)	Manually drawn circumference	TAV over 4 cardiac cycles
Ozen et al. (2014)	$D/2*\pi$ in longitudinal plane	Mean TAV over 2 or 3 cardiac cycles
Jakimovski et al. (2017)	Manually drawn circumference	Mean TAV over 4 s
Yeoh et al. (2017)	Manually drawn circumference	Mean TAV over 3 s
Chambers et al. (2014)	$D/2*\pi$ in longitudinal plane	Mean TAV over 4 or 5 cardiac cycles
Schreiber et al. (2003)	$D/2*\pi$ in transverse plane	Not described
Monti et al. (2011)	Manually drawn circumference	TAV over 3 cardiac cycles at end of expiration
Ciuti et al. (2013)	$D/2*\pi$ in transverse plane	Quality Doppler profile velocity

CSA = cross-sectional area; *D* = diameter; TAV = time-averaged velocity.

In the past two decades, studies have attempted to calculate the venous BFV with various measurement methods (Table 1). Because of the thin and malleable venous wall, the shape of the vein is not always geometrically circular (Gill 1985). Therefore, the use of cross-sectional diameter as a cross-sectional measure probably underestimates the size of the vessel (Chambers et al. 2014). In response to the limitations of DS use in venous flow quantification, technical considerations have been proposed to rectify the discrepancies and improve the reproducibility of the scans (Nicolaides et al. 2011). Additionally, several groups have resorted to manual CSA segmentation and manual spectral waveform tracing (Jakimovski et al. 2017; Monti et al. 2014). However, a general consensus on extracranial venous BFV measurement and calculation is currently lacking. Although current Doppler units are equipped with automated measurement software packages, the DS physics principles for velocity, CSA and BFV calculation are based on previously validated arterial anatomy and physiology. Use of the aforementioned automated BFV calculation on the irregular and complex venous system could potentially provide erroneous data.

On this background, we aimed to compare IJV BFV calculated manually with that obtained using the automated DS unit methodology. As a benchmark comparison, manual and semi-automated DS unit-computed volumes of the common carotid artery (CCA) were obtained.

METHODS

Clinical and demographic characteristics

The participants in this analysis were prospectively enrolled in the Combined Extra- and Intra-cranial Venous Doppler and MRI Evaluation in Healthy Individuals (CEIVD-MRI-HI) study. Study inclusion criteria were (i) age between 18 and 89 y and (ii) qualification on a health screen questionnaire. The exclusion criteria were (i) pre-existing medical conditions known to be associated with brain pathology (*e.g.,* cerebrovascular disease, alcohol abuse and other neurologic diseases), (ii) history of cerebral vascular malformations and congenital malformations (*i.e.,* Klippel–Trenaunay, Parkes–Weber, Servelle–Martorell and Budd–Chiari syndromes), and (iii) pregnancy or nursing. This study was approved by the local institutional review board, and informed consent was obtained from all participants enrolled in the study.

Doppler sonography acquisition

An echo-color Doppler sonography system (Biosound My Lab 25 Gold, Esaote, Genoa, Liguria, Italy) equipped with 2.5-MHz and 7.5- to 10-MHz transducers was used for extra- and intra- cranial examinations. The 7.5- to 10-MHz linear probe was used to examine the IJV and CCA. DS unit velocity, color flow direction and axial and vertical spatial resolution were tested regularly using a Mini-Doppler Phantom unit (Model 1430, Gammex, Middleton, WI, USA).

All sonographic examinations were performed by the same registered vascular technologist with 27 y of experience (K.M.). Participants drank 16 oz of water within 1 h before the study. The participants were placed on a hydraulic chair and instructed to lie in a supine position for a minimum of 3 min before scanning started. Warm Aquasonic 100 water-soluble, hypo-allergenic transmission gel was applied to the neck area, with the head placed in a neutral, straightforward position. The IJV was scanned in the transverse plane to assess for regions of interest. IJV volume was assessed at three levels bilaterally: just below the facial vein entry (J3), in the approximately mid-thyroid region (J2) and approximately 1 cm above the IJV valve (J1). At each IJV level, a transverse CSA measurement followed by the longitudinal image was recorded. Manual waveform tracing over a 4-s period was used to calculate the time-averaged velocity (TAV). To shorten the exam, the measurements taken in the longitudinal view were calculated after completion of the exam. An angled color box during longitudinal image acquisition, angle of incidence at or between 45° and 60° with angle correction bar parallel to vessel walls and spectral gate size, adjusted accordingly within the lumen per standard vascular protocol, were maintained. The sample gate was open to maximal size yet maintained within the vessel lumen to avoid vessel wall artifacts in the waveform.

With the participant in the supine position, left and right CCA blood flow was measured approximately 1.5 cm before the bifurcation and at the proximal neck level of the CCA. As for the vein measurements, the 4-s longitudinal TAV image was also recorded. DS frequency,