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● *Original Contribution*

SPLANCHNIC ARTERIAL BLOOD FLOW IS SIGNIFICANTLY INFLUENCED BY BREATHING—ASSESSMENT BY DUPLEX-DOPPLER ULTRASOUND

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Abstract—Duplex ultrasound is established for the assessment of mesenteric ischemia but potential influences of breathing on mesenteric arterial blood velocity have not been investigated so far. In 100 patients without abdominal diseases (39 men; age 59.4 ± 18.0 years), peak systolic (PSV), end diastolic velocity (EDV) and resistance index (RI) were assessed in the celiac trunk (CT) and the superior mesenteric artery (SMA) by Doppler ultrasound during expiration and deep inspiration. Expiratory PSVs in the CT and the SMA (153.4 ± 42.5 and 145.3 ± 39.5 cm/s) were significantly higher than inspiratory velocities (135.4 ± 36.8 and 131.9 ± 42.2 cm/s, $p < 0.0001$ and $p = 0.0002$), with expiratory PSVs exceeding inspiratory PSVs in more than 75% of patients. The mean percentage of PSV-variation was 21.5% ± 15.3% and 24.6% ± 19.1%, respectively. The study demonstrates that breathing may exert considerable periodic effects on splanchnic arterial hemodynamics. We, therefore, recommend that to prevent an underestimation of arterial stenosis, mesenteric Doppler ultrasound should be performed during expiration. (E-mail: arne.schneider@lrz.tum.de)   © 2010 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Ultrasound, Duplex-Doppler, Stenosis, Splanchnic artery, Ischemia.**

INTRODUCTION

Duplex-Doppler measurement of splanchnic arteries is an established technique for the assessment of suspected vascular stenoses. Pulsed Doppler scanning is able to detect significant stenoses with more than 90% accuracy (Mitchell and Moneta 2006; Moneta et al. 1991, 1993). One of the most common Doppler flow parameters is the systolic peak flow velocity. Roughly, a splachnic peak velocity of more than 250 cm/s is considered highly indicative of a severely compromised blood flow (Moneta et al. 1991; Zwolak et al. 1998). The "resistance index", calculated from peak systolic and endiastolic flow velocities, is an additional parameter and independent from the Doppler angle. Though it is less evaluated for splanchnic arteries, it may be of help in cases when a suboptimal Doppler angle obviates a reliable measurement of absolute flow velocities. However, compliant patients may help to improve visualisation and Doppler assessment by deep inspiration or a change from supine to an upright position.

The majority of previous publications on studies that aimed at defining "reference" values of splanchnic flow velocities did not state in which phase of breathing measurements were performed (Dietrich et al. 2007). Yet, breathing may exert relevant effects on hemodynamic parameters and, consequently, influence Doppler flow measurements. Additionally, the celiac trunk is located in a peculiar topographic region: the arcuate ligament spans in between the diaphragmatic crura directly above the vessel and may cause extraluminal stenosis, especially during expiration. If such patients complain of postprandial abdominal pain, celiac artery compression (Dunbar syndrome), a temporary compression of the celiac trunk by the arcuate ligament causing significant vascular stenosis and ischemia, might be an explanation (Dunbar et al. 1965). On the other hand, there is an ongoing debate of whether mesenteric compression syndromes of the celiac trunk or the superior mesenteric artery really account for clinical symptoms or whether they are solely pathophysiologic hypotheses.

Beyond Dunbar's syndrome, data on the physiologic effects of breathing on hemodynamics in splanchnic arteries are lacking. For this reason, we aimed to define

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the spectrum of splanchnic flow velocities in asymptomatic patients during in- and expiration.

PATIENTS AND METHODS

One hundred consecutive patients were prospectively evaluated. Patients underwent abdominal ultrasound for the evaluation of nonabdominal conditions, *e.g.*, urinary infections and neurologic diseases. None of the patients suffered acute or chronic gastrointestinal diseases. Patients with major abdominal surgery (bowel resection, pancreatobiliary or hepatic surgery) were excluded, as were patients with severe chronic or acute heart failure (cardiac ejection fraction $<$40%) or cardiac arrhythmia. Abdominal ultrasound was performed using a Hitachi EUB 8500 ultrasound system (Hitachi Medical Systems, Wiesbaden, Germany). Doppler measurements were performed by three experienced physicians (A.S., H.S. and J.T.) with a 3.5 MHz transducer. Excellent interobserver agreement had been documented by performing Doppler measurements in eight volunteers with $K \geq 0.75$.

Generally, patients underwent a complete sonographic workup of the upper abdomen in the supine position after a minimum fast of 8 h. Additional Duplex-Doppler of the celiac trunk (CT) and the superior mesenteric artery (SMA) was first performed during expiratory and, second, during inspiratory breath hold ($<$30 s) (Fig.1). Patients were explicitly briefed to avoid a Valsalva maneuver both during in- and expiration. Such an attempt to exhale forcefully with the upper airways closed would have caused a considerable unphysiologic increase of intra-abdominal pressure. The sample volume was placed 2 ± 1 cm distal to the origin of the vessel and the dimension was set at $\geq$50% of the vessel diameter. For the celiac trunk, the sampling volume was positioned proximal to the splitting into its branches. All investigators took meticulous care to achieve a Doppler angle of less than 40 degrees, applying an adapted angulation of the transducer.

Additionally, angulation of the transducer during inspiration was individually optimized until this Doppler angle corresponded with the angle used for expiratory measurements. After adjustment of the pulse repetition frequency and the gain, expiratory and inspiratory peak systolic (PSV-E, PSV-I) and end diastolic velocities (EDV-E, EDV-I) [cm/s] were assessed and the resistance indices (RI-E, RI-I) were calculated. Primary variable was the mean of three consecutive measurements of each parameter during in- and expiration.

In addition, the individual percentage of peak flow variation between in- and expiration was calculated according to the equation $([PSVmax - PSVmin]/PSVmax) \times 100$, where PSVmax and PSVmin depended on whether the expiratory or the inspiratory peak flow was higher.

Comparison of blood flow velocities during in- and expiration in individual patients was performed with the Wilcoxon matched pairs test. The Mann-Whitney test

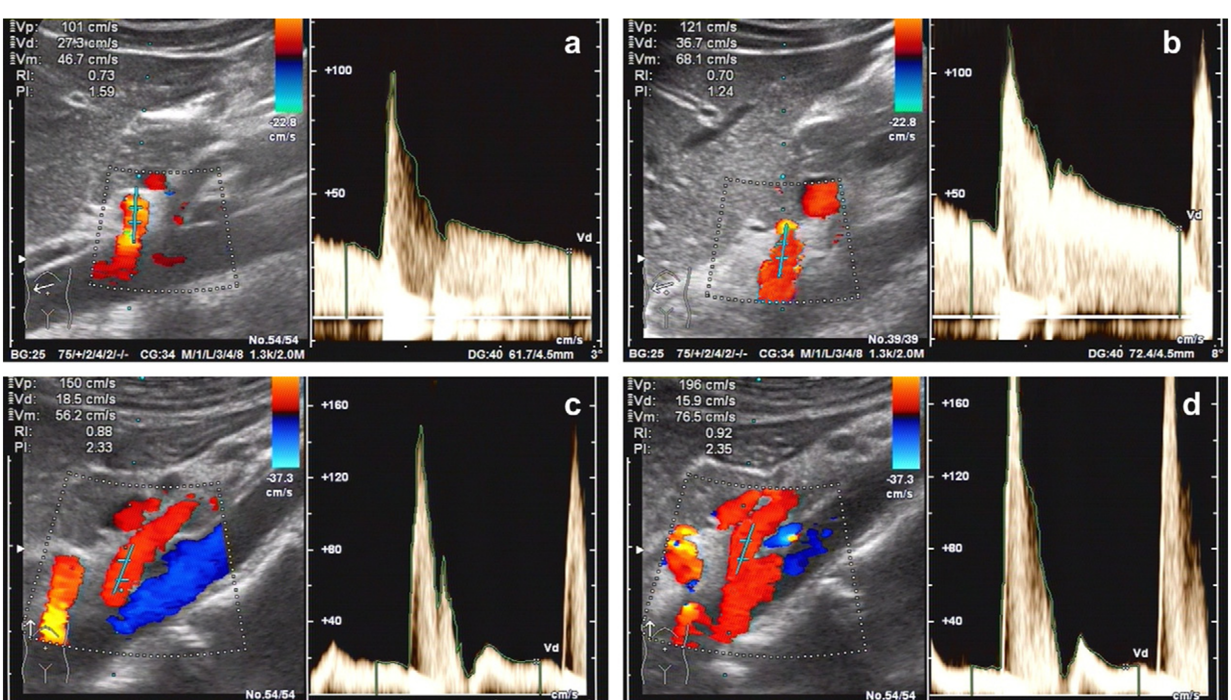

Fig. 1. Color and duplex Doppler images of the celiac trunk during inspiration (a) and expiration (b) as well as the superior mesenteric artery during in- (c) and expiration (d). Doppler angles are shown in the lower right corner of the images.

was used for the comparison among different groups. Nonparametric Spearman-correlation was performed for the comparison of blood flow parameters with age. A $p \leq 0.05$ was considered significant. Calculations were performed with GraphPad Prism Vers. 4.01 (GraphPad Software Inc., La Jolla, CA, USA). Patients provided informed consent to participate in the study. The study was performed in accordance with the principles of the Declaration of Helsinki.

RESULTS

Thirty-nine men and 61 women were studied (age 59.4 ± 18.0 years). Mean body weight and body mass index were 66.1 ±12.4 kg and 23.5 ± 4.0 kg/m^2, respectively. In the celiac trunk, PSV-E (mean ± SD: 153.4 ± 42.5 cm/s [range 83.1–285.0 cm/s]) and EDV-E (42.5 ± 21.8 cm/s [3.9–71.2 cm/s]) were significantly higher than PSV-I (135.4 ± 36.8 cm/s, $p < 0.0001$ [68.0–272.0 cm/s]) and EDV-I (36.7 ± 17.7 cm/s [3.4–67.4 cm/s], $p = 0.003$) (Fig. 2). The absolute difference between PSV-E and PSV-I was 18.0 ± 42.9 cm/s [–8.4 to 196.2 cm/s]. PSV-E exceeded PSV-I in 78% of patients. Among pooled individual patients, the mean percentage of PSV-variation between in- and expiration was 21.5 ± 15.3% (range 0.4%–81.0%). Particularly, 21 of 100 patients showed an individual difference between PSV-E and PSV-I exceeding 50 cm/s.

PSV-E in the SMA was also significantly higher than the inspiratory values (145.3 ± 39.5 [69.1–260.0 cm/s] vs. 131.9 ± 42.2 cm/s [61.1–245.0 cm/s], $p = 0.0002$), whereas EDV-E and EDV-I were roughly similar (24.5 ± 13.1 [2.8–72.0 cm/s] vs. 23.2 ± 10.7 cm/s [6.9–65.8 cm/s], $p = 0.26$) (Fig. 3). Seventy-seven percent (77%) of patients had a positive delta between PSV-E and PSV-I in the AMS, exceeding 50 cm/s in 15 of 100 patients. The mean percentage of PSV-variation was 24.6% ± 19.1% (0.0%–86.3%) (Fig. 4). Neither CT nor AMS measurements detected significant ex- nor inspiratory differences for the resistance indices (CT: 0.73 ± 0.09 vs. 0.74 ± 0.09, $p = 0.29$; SMA: 0.83 ± 0.08 vs. 0.82 ± 0.07, $p = 0.27$).

Correlation analysis showed that only the EDV decreased significantly with advancing age (r = –0.32 to –0.36). Corresponding resistance indices increased with age (r = 0.33 to 0.43) (Table 1). Neither weight nor body mass index of the study patients correlated with the Doppler flow parameters.

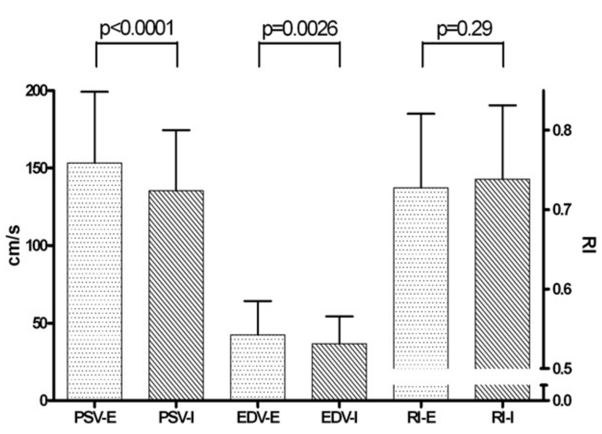

Fig. 2. Peak systolic velocity (PSV), end diastolic velocity (EDV) and resistance index (RI) during expiration (-E) and inspiration (-I) in the celiac trunk (mean ± SD).

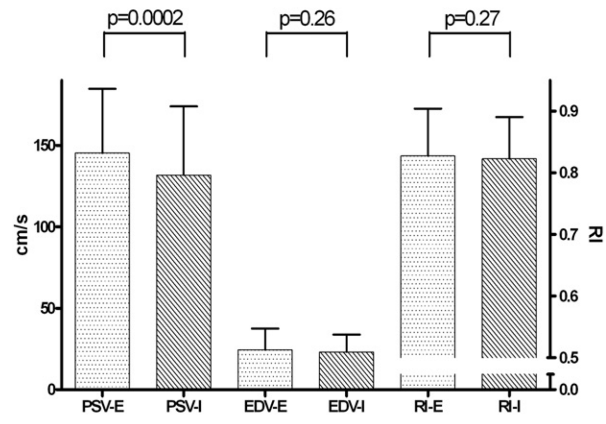

Fig. 3. Peak systolic velocity (PSV), end diastolic velocity (EDV) and resistance index (RI) during expiration (-E) and inspiration (-I) in the superior mesenteric artery (mean ± SD).

DISCUSSION

Our results of duplex-Doppler measurements add the largest group of participants to previously published reports on reference values for blood flow velocities in

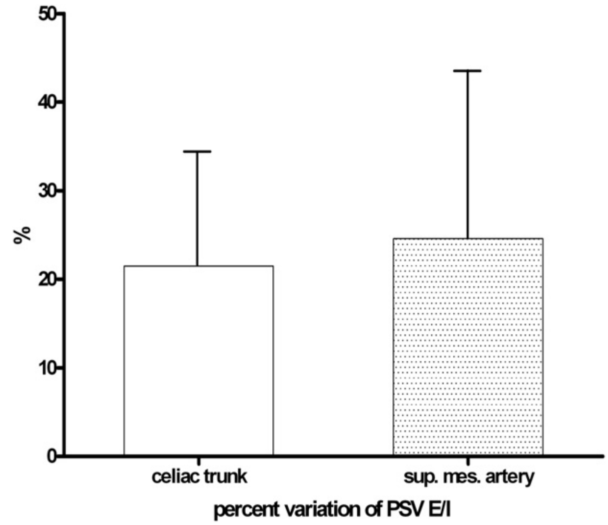

Fig. 4. Percentage of peak flow variation between in- and expiration in the celiac trunk and the superior mesenteric artery (mean ± SD).

Table 1. Correlation of flow parameters with age

		R	p
Celiac trunc	PSV-E	n.s.	n.s.
	EDV-E	−0.33	0.001
	RI-E	0.43	<0.0001
	PSV-I	n.s.	n.s.
	EDV-I	−0.32	0.001
	RI-I	0.33	0.0009
Superior mesenteric artery	PSV-E	n.s.	n.s.
	EDV-E	−0.36	0.0003
	RI-E	0.33	0.0009
	PSV-I	n.s.	n.s.
	EDV-I	n.s.	n.s.
	RI-I	n.s.	n.s.

PSV = peak systolic velocity; EDV= end diastolic velocity; RI = resistance index; r = correlation coefficient.

the celiac trunk and the superior mesenteric artery (Dietrich et al. 2007). Generally, data of this study are consistent with former publications. However, the majority of studies did not report a standardized breath hold technique and breathing position in which measurements were performed. Therefore, this study further highlights this aspect and documents a relevant effect of breathing on the blood flow velocity in splanchnic arteries. Duplex ultrasound of mesenteric arteries is a widely available method for the noninvasive and real-time assessment of splanchnic hemodynamics. Though data are lacking, an optimal assessment of blood flow velocity succeeds in about 90% of patients. Mesenteric ischemia is a rare but relevant cause for abdominal symptoms. Whereas an isolated stenosis of the superior mesenteric artery can be effectively compensated by collaterals, a combination of splanchnic stenoses may cause chronic ischemia. The most reliable and accepted parameter for significant stenosis is a peak velocity exceeding 275 cm/s in the superior mesenteric artery and 200 cm/s in the celiac trunk (Perko 2001). To date, computed tomography or magnetic resonance imaging angiographies are performed in patients with a high probability of mesenteric artery stenosis. However, due to the fact that the above mentioned criteria bear a sensitivity of more than 89% and a specificity of more than 92%, duplex ultrasound is a reliable and less costly option in patients with a low pretest probability of a pathologic result, *e.g.*, those with unspecific symptoms and lacking risk factors for cardiovascular diseases (Moneta et al. 1991; Harward et al. 1993; Gentile et al. 1995).

Physicians who perform Doppler ultrasound flowmetry often recognize a movement of splanchnic arteries during breathing. This notably applies for the celiac trunk that originates from the aorta close to the crura of the diaphragm and the arcuate ligament. Both the celiac trunk and the superior mesenteric artery are located in the retroperitoneum and provide the blood supply for intraperitoneal organs that move synchronously with respiration. These physiologic changes in the course of the vessels probably exert influences on hemodynamic parameters. During expiration, the arcuate ligament may cause substantial extraluminal compression of the celiac trunk, resulting in temporary splanchnic ischemia and abdominal pain, the so-called Dunbar- or celiac compression syndrome.

Previous investigators have shown that visceral blood flow is influenced by food intake and, to a lesser degree, by physical activity and breathing frequency (Someya et al. 2007; Dauzat et al. 1994; Moneta et al. 1988, Perko et al. 1998). During renal Doppler flowmetry, the Valsalva maneuver, a vigorous effort to exhale air while keeping the mesopharynx closed, decreases the diastolic flow velocity and, consequently, alters the resistance index (Takano et al. 2001). Whether the same hemodynamic changes occur in splanchnic arteries during the maneuver is unknown.

In general, systemic arterial blood flow rates and pressures are lower by up to 10% during inspiration compared with expiration (Bjurstedt et al. 1980). This phenomenon is multifactorial and can be attributed to changes in the resistance of pulmonary vessels, cardiac pre- and afterload and negative intrathoracic pressure (Innes et al. 1993).

Our results do support these considerations. In the majority of patients, peak systolic blood flow was significantly higher during expiration than during deep inspiration. We found a remarkable variation between in- and expiratory peak velocities, namely 21.5% in the CT and 24.6% in the SMA. This applied for both CT and SMA and could be explained with a systemic increase of the arterial blood flow rate in the expiratory position. In the present study, the difference between expiratory and inspiratory blood flow velocities even exceeded 50 cm/s in 21 patients (CT) and 15 patients (SMA), respectively. Since we followed strict criteria for the Doppler recordings, regarding *e.g.*, the Doppler angle and the sampling volume, these differences cannot be ascribed to errors of measurement.

Whereas smaller breath-associated changes of flow might be negligible, we believe that an over- or underestimation of peak velocities of 50 cm/s or more can be clinically relevant. Though general guidelines are lacking and expert recommendations are heterogeneous, most physicians aim to perform mesenteric duplex ultrasound with the patient keeping a relaxed resting expiratory position (Dietrich et al. 2001; Perko 2001). However, in many patients, adequate duplex-Doppler ultrasound of mesenteric blood flow requires different respiratory maneuvers to achieve an optimal Doppler angle and/or visualisation of the vessel. Therefore, a peak systolic blood flow of 150 cm/s in the CT and 250 cm/s in the SMA, acquired during inspiration, may cause an underestimation of arterial stenosis. On the other hand, if flow velocities are recorded in a resting expiratory position (that roughly compares with the expiratory position in our study), the risk of missing relevant arterial stenosis is low. The study also demonstrates that the "celiac compression syndrome" is partly physiologic because all patients were asymptomatic in terms of abdominal symptoms. Additionally, PSVs exceeding 200–250 cm/s are partially encountered even in asymptomatic young persons.

Further analysis of our data showed that only diastolic flow velocities correlated moderately (inversely) with increasing age whereas systolic flow parameters remained constant. Data on the effect of age on splanchnic artery velocities are lacking but a study focusing on Duplex ultrasound of internal carotid arteries found a significant inverse correlation between age and EDV (Spencer et al. 2001). The authors explained this finding with an increasing vessel diameter that finally results in a decrease in velocity. Since we did not measure the vessel diameter, this study is unable to add auxiliary information on this hypothesis.

In conclusion, we were able to show that splanchnic arterial blood flow can be subject to a considerable leverage during the breathing cycle. Breathing-associated variations of flow velocities should be taken into consideration in patients with Doppler findings suggestive of vascular stenosis before a definitive diagnosis is stated. Physicians should aim to achieve optimal conditions for Duplex ultrasound of visceral arteries during a resting expiratory position because this minimizes false-negative results.

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