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●*Original Contribution*

COMPARISON OF TRANS- AND INTRA-ABDOMINAL DUPLEX EXAMINATIONS OF THE SPLANCHNIC CIRCULATION

TRUDY A. DELAHUNT,[†] ROBERT H. GEELKERKEN,[†] JO HERMANS,[‡] JARY M. VAN BAALEN,[†] ANDY J. VAUGHAN* and J. HAJO VAN BOCKEL[†]

[†]Departments of Surgery and [‡]Statistics, University Hospital Leiden, Leiden, The Netherlands; and *Aloka Europe, Moofddorp, The Netherlands

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Abstract—To evaluate the influence of the technical problems experienced when scanning transabdominally, a comparison was made between transabdominal and intra-abdominal Doppler parameters of the aorta and the splanchnic arteries. Peroperative color duplex sonography of the abdominal aorta and the splanchnic arteries was performed on 25 patients who were undergoing abdominal vascular reconstructive surgery under stabilized standardised anaesthesia. Doppler samples and diameter measurements were taken of the aorta, celiac, common hepatic, splenic, superior and inferior mesenteric arteries, both trans- and intra-abdominally. Significantly higher velocities were recorded in the celiac artery during intra-abdominal examinations. There was a trend toward higher recorded velocities in the other vessels. There was also a significant difference in the diameter measurements of most of the vessels. The trans- and intra-abdominal results were not always equivalent. The differences were not due to technical aspects. Transabdominal duplex sonography is difficult and may not be completely accurate in detecting quantitative flow parameters in the splanchnic arteries.

Key Words: **Duplex, Splanchnic circulation, Transabdominal, Intra-abdominal.**

INTRODUCTION

Chronic splanchnic syndrome is defined as symptomatic obliterative splanchnic disease. The diagnosis of chronic splanchnic syndrome remains a challenge as the symptoms are not specific and present available diagnostic tests are unable to supply a definitive diagnosis (Blebea 1992; Roobottom et al. 1993). Duplex scanning of the celiac and superior mesenteric arteries is advocated as a noninvasive method of evaluating the splanchnic vasculature (Healy et al. 1992; Mallek et al. 1993; Moneta et al. 1993). However, there has been an inconsistency in the results of studies performed using transabdominal duplex, with a wide range of normal and abnormal flow velocities and volumes reported in the literature (Geelkerken and van Bockel 1995). This may be due to physiological differences between patients, or technical difficulties inherent in transabdominal duplex, or both (Burns 1989; Perko and Just 1993; Sabbá et al. 1990).

Intra-abdominal duplex, on the other hand, has less potential for inaccuracies due to technical difficulties. Intra-abdominal duplex provides easy access to the abdominal vasculature. A higher frequency probe can be used with the resultant improved image quality. This improved resolution results in clearer visualisation of the vessel walls. Consequently, it should increase the accuracy of the diameter measurements. The improved resolution and greater magnification obtained intra-abdominally should also lead to a more accurate assessment of the beam-to-flow angle, which increases the probability of accurate velocity calculations. Moreover, respiration can be carefully controlled and any influence on the velocity can be noted (Taylor et al. 1987). Theoretically, intra-abdominal duplex should be the gold standard for the evaluation of the celiac and superior mesenteric arteries.

This study was initiated to compare the splanchnic duplex results obtained transabdominally with those obtained intra-abdominally in the same patients, under standard conditions, in the same locations and with the same technique. We could then evaluate the extent to which the technical difficulties inherent in transabdominal scanning influenced the duplex results. We ex-

Address correspondence to: R. H. Geelkerken, Department of Surgery, Medisch Spectrum Twente, P.O. Box 50.000, 7500 KA Enschede, The Netherlands.

pected no significant differences between the velocity measurements other than a possibly greater standard deviation with the less accurate transabdominal method.

METHODS

Peroperative color duplex sonography of the abdominal aorta and the splanchnic arteries was performed on 25 patients under stabilized standardised anaesthesia, who were undergoing abdominal vascular reconstructive surgery. The indications for operation were aortic infrarenal aneurysmal disease (14 patients), distal aortic–iliac obliterative disease (6 patients), renovascular disease (3 patients) and chronic splanchnic syndrome (2 patients). The average age of the patients was 65 years, ranging from 39 to 81 years. Preoperatively, all 25 patients underwent multiplane intra-arterial digital subtraction angiography of the abdominal aorta and its branches (Philips 3000 Integris System, Philips) (Aarts et al. 1993). All patients had a normal proximal abdominal aorta and 16 patients had a normal splanchnic inflow (celiac and superior mesenteric artery). Both normal and stenotic splanchnic arteries were included in this study. The procedures were explained in detail to the patients and consent was obtained from them in accordance with the hospital's ethics committee.

Anaesthesia

All 25 patients received standardised anaesthesia before the transabdominal duplex scanning started. A pulmonary artery catheter (Viggo Spectramed, Ohmeda, Hatfield, UK) was introduced immediately after the start of the anaesthesia. The 25 patients were intubated and artificially ventilated with a volume-steered mechanical ventilator. Intermittent positive pressure ventilation was applied with 10 mg/kg tidal volume and a frequency of 12–14 beats per minute, adjusted to keep the end-tidal CO_2 between 3.5 to 4.0 kPa. All patients were stable with regard to pulse rate, blood pressure, urinary production, central venous pressure, pulmonary artery wedge pressure, cardiac output, systemic vascular resistance and volume and frequency of respiration during the trans- and intra-abdominal duplex measurements.

Duplex scanning

The patients were scanned using the same Aloka 2000 (Biomedic, Almere, The Netherlands). The transabdominal duplex scanning was performed using a 3.5 MHz convex sector probe. The intra-abdominal duplex examinations were performed with a 7.5 MHz steerable linear array probe. The transabdominal duplex examinations were performed by one technologist (T. A. D.) who had no prior knowledge of any angiographic results. The intra-abdominal duplex examinations were performed by one surgeon (R. H. G.), who was blinded to the splanchnic angiography and to the transabdominal duplex results.

In both transabdominal and intra-abdominal duplex examinations, the Doppler samples were taken with a sample length of 5 mm. Velocity measurements were taken with the smallest flow-to-beam angle possible. No measurements were accepted if the angle was greater than 60°, which resulted in the exclusion of some Doppler velocity measurements. The one most optimal B-mode image and Doppler spectrum was used for the analysis. All duplex measurements were recorded on videotape for later evaluation.

Transabdominal imaging technique

The aorta was imaged in a longitudinal section, and a Doppler sample of the aorta was taken at the level of the superior mesenteric artery. The celiac artery was then located either in the transverse or longitudinal section, whichever allowed optimal visualisation. The entire vessel was imaged and the most optimal Doppler sample was obtained within 0.5 cm of the vessel origin. The probe was then manipulated in the transverse section until the "seagull sign," representing the common hepatic and splenic arteries, was obtained. Further manipulation was usually necessary to obtain an angle of $<60°$ for each vessel. Provided that this could be achieved a Doppler sample was then taken within the first centimeter from both the common hepatic and splenic arteries. The superior mesenteric artery was then located. It is usually seen optimally in a longitudinal section, although the origin can sometimes be well-visualised in a transverse section. The most optimal Doppler sample was obtained within 0.5 cm of the vessel origin. The aorta was then scanned in a transverse section and, with the aid of the color flow mapping, the inferior mesenteric artery was located and a velocity sample was obtained at its origin. All Doppler signals were taken during the expiration phase of normal artificial respiration during stable anesthesia in a supine position. It was found that in most cases the Doppler signal was more readily obtained during the expiratory phase of respiration, as the vessels were more clearly visualised, particularly in the case of the celiac artery.

Intra-abdominal imaging technique

A sterile plastic sheath was placed over the cable and the probe was covered in a sterile condom with sufficient sterile gel in the condom to act as a stand-off from the vessel. After midline laparotomy, the vessels were located either visually or with the aid of palpation and the probe was then placed directly over them. The same locations were used to obtain Doppler samples as in the transabdominal duplex study. The Doppler signals were taken during the expiration phase of normal artificial respiration during stable anesthesia in a supine position.

Parameters

The parameters measured and reported were the peak systolic velocity (PSV), the peak diastolic reverse velocity (PDRV), the peak diastolic forward velocity (PDFV) the end-diastolic velocity (EDV) (in centimeters per second); the acceleration index (AI), the deceleration index (DI) in cm/s^2, the pulsatility index (PI), the resistive index (RI), the diameter of the artery (DA) at the level of the Doppler sample (in millimeters); and the flow-to-beam angle (SA).

The AI was defined as PSV/systolic rise time. The DI was defined as PSV/systolic deceleration time to the diastolic notch. The PI was defined as peak-to-peak velocity/mean velocity (Johnston 1993). The RI was defined as (PSV − EDV)/PSV.

Data management and analysis

All data were entered into a computer database. We did not assume more accurate results for either the trans- or intra-abdominal methods. Consequently, to statistically assess the differences between the paired data (trans- vs. intra-), the two-tailed paired t test was used and reported. The Wilcoxon signed rank test was also used and gave very similar results. A p value of less than 0.05 was considered significant, and a value less than 0.10 was considered to indicate a trend.

RESULTS

The only significant difference noted in the abdominal aorta between trans- and intra-abdominal parameters was the diameter measurement (Table 1). There were 18 aortas measured both trans- and intra-abdominally and the mean transabdominal measurement was 23 mm with a standard deviation of 4 mm compared to the intra-abdominal measurement of 21 mm with a standard deviation of 4 mm (relative difference 9%, p = 0.03). There was overall agreement between the aortic measurements including the standard deviations. However, there was a trend toward lower intra-abdominal PDRV, DI and PI.

More significant differences were noted in the celiac artery with higher velocities recorded intra-abdominally (Table 2). There were 22 measurements available for comparison. The mean PSVs were 141 cm/s transabdominally and 177 cm/s intra-abdominally (rel-

Table 1. Trans- and intra-abdominally measured Doppler parameters of the abdominal aorta and the origins of the superior and inferior mesenteric arteries.

	Aorta							Superior mesenteric artery							Inferior mesenteric artery						
		Transabdominal		Intra-abdominal		Difference			Transabdominal		Intra-abdominal		Difference			Transabdominal		Intra-abdominal		Difference	
Parameters	n	Mean	SD	Mean	SD	SEM	p	n	Mean	SD	Mean	SD	SEM	p	n	Mean	SD	Mean	SD	SEM	p
PSV	19	50	15	53	18	3.7	0.50	24	121	55	140	59	9.9	0.07	14	89	55	93	57	14	0.81
PDRV	13	14	10	9.1	8.3	2.3	0.08	16	14	13	18	13	2.2	0.12	10	6.5	9.4	7.7	7.5	2.5	0.64
PDFV	18	13	7.3	13	9.5	2.1	0.96	23	27	21	33	27	2.9	0.06	14	19	14	17	7.5	3.5	0.37
EDV	19	7.4	4.6	8.5	6.7	1.2	0.34	24	15	15	18	20	2.0	0.20	14	11	11	11	12	3.9	1.0
AI	18	845	390	799	440	99	0.65	22	1739	1027	1623	730	196	0.65	13	1391	1048	1808	1507	474	0.40
DI	18	186	49	153	61	17	0.07	23	469	244	517	230	44	0.29	13	313	156	375	218	39	0.14
PI	19	2.8	0.95	2.4	0.75	0.16	0.06	23	2.6	0.52	2.7	0.70	0.10	0.59	13	2.5	0.63	2.4	0.74	0.21	0.64
RI	19	0.86	0.06	0.84	0.10	0.02	0.49	24	0.87	0.07	0.88	0.08	0.01	0.54	13	0.88	0.09	0.86	0.14	0.04	0.67
DA	18	23	4.0	21	4.3	0.89	0.03	21	8.3	2.9	7.1	1.9	0.54	0.04	12	3.2	1.3	2.5	1.0	0.28	0.04
SA	19	50	7.1	47	10	2.6	0.21	24	24	18	24	16	3.8	0.92	13	29	17	33	16	6.9	0.53

SD: standard deviation; SEM: standard error of the mean; p: two-tailed paired t test. See text for parameter abbreviations.

Table 2. Trans- and intra-abdominally measured Doppler parameters of the origins of the celiac, hepatic and splenic arteries.

	Celiac artery							Common hepatic artery							Splenic artery						
		Transabdominal		Intra-abdominal		Difference			Transabdominal		Intra-abdominal		Difference			Transabdominal		Intra-abdominal		Difference	
Parameters	n	Mean	SD	Mean	SD	SEM	p	n	Mean	SD	Mean	SD	SEM	p	n	Mean	SD	Mean	SD	SEM	p
PSV	22	141	61	177	64	14	0.02	11	99	40	141	65	21	0.08	8	111	65	104	62	27	0.79
PDRV	—							—							—						
PDFV	22	65	35	83	35	8.2	0.04	11	43	19	65	38	12	0.11	7	52	32	42	27	12	0.44
EDV	22	40	24	52	25	6.1	0.05	10	26	13	41	28	8.9	0.12	8	31	19	24	14	7.1	0.39
AI	22	2197	1948	1867	980	413	0.55	10	2026	1314	2397	1978	667	0.95	8	1689	1500	1537	1913	915	0.87
DI	22	347	153	462	236	48	0.03	10	260	159	402	361	128	0.30	8	306	187	260	179	58	0.46
PI	22	1.4	0.33	1.4	0.28	0.07	0.60	10	1.6	0.45	1.4	0.31	0.14	0.38	8	1.4	0.24	1.5	0.47	0.15	0.37
RI	22	0.71	0.09	0.72	0.08	0.02	0.70	10	0.74	0.07	0.73	0.08	0.02	0.61	8	0.72	0.07	0.74	0.12	0.04	0.51
DA	21	7.7	2.2	7.0	1.4	0.34	0.05	10	6.1	1.6	5.9	1.4	0.65	0.76	8	7.1	1.5	5.1	1.5	0.73	0.03
SA	22	19	15	16	15	3.9	0.50	11	51	10	43	11	4.8	0.12	8	41	11	45	10	6.7	0.61

SD: standard deviation; SEM: standard error of the mean; p: two-tailed paired t test. See text for parameter abbreviations.

ative difference 26%, $p = 0.02$). The mean PDFVs were 65 cm/s transabdominally and 83 cm/s intra-abdominally (relative difference 28%, $p = 0.04$). The mean EDVs were 40 cm/s transabdominally and 52 cm/s intra-abdominally (relative difference 30%, $p = 0.05$). The trans- and intra-abdominal obtained standard deviations were comparable. The mean transabdominal diameter measurement was 8 mm compared to the intra-abdominal measurement of 7 mm (relative difference 13%, $p = 0.05$). The common hepatic artery showed a trend toward lower transabdominal PSV measurements (relative difference 42%, $p = 0.08$). No significant differences were noted in the splenic artery with the exception of the DA (relative difference 29%, $p = 0.03$). However, the number of these vessels available for analysis was smaller.

There were no significant differences in the velocity measurements of the superior mesenteric and inferior mesenteric arteries (Table 1). However, transabdominally there was a trend toward lower PSV and PDFV measurements at the origin of the superior mesenteric artery. The trans- and intra-abdominal obtained standard deviations were comparable. Again, there was a significant difference in the diameter measurements of both arteries trans- and intra-abdominally. The mean superior mesenteric artery measured 8 mm and 7 mm, respectively. The inferior mesenteric artery measured 3 mm and 2 mm, respectively (relative difference $p = 0.04$ for both superior and inferior mesenteric arteries). The statistical analysis is summarized in Table 3.

DISCUSSION

A significant underestimation of the velocities was recorded transabdominally in the celiac artery (Tables 2 and 3). In the superior mesenteric artery, a trend toward lower velocities was noted when measured transabdominally (Tables 1 and 3). A wider range of velocities could have been anticipated when scanning transabdominally as there are more problems encountered in obtaining the signal than by scanning intra-abdominally. However, the range in the standard deviations was not significantly different for both intra- and transabdominal results. Moreover, there was no significant difference between the intra- and transabdominal velocities measured in the aorta (Tables 1 and 3). These findings would suggest that there is a more specific cause for the lower velocities recorded transabdominally, particularly in the celiac artery and to a lesser extent in the superior mesenteric artery. Although the paired Doppler parameters of the six arteries evaluated were not available for all 25 patients, mostly due to exclusion of velocity measurements because of a flow-to-beam angle above 60°, we do not

Table 3. Sumary of statistical analysis of differences between trans- and intra-abdominally measured Doppler parameters.

	Artery					
Parameter	Abdominal aorta	Celiac	Common hepatic	Splenic	Superior mesenteric	Inferior mesenteric
PSV	0.50	0.02	0.08	0.79	0.07	0.81
PDRV	0.08	—	—	—	0.12	0.64
PDFV	0.96	0.04	0.11	0.44	0.06	0.37
EDV	0.34	0.05	0.12	0.39	0.20	1.0
AI	0.65	0.55	0.95	0.87	0.65	0.40
DI	0.07	0.03	0.30	0.46	0.29	0.14
PI	0.06	0.60	0.38	0.37	0.59	0.64
RI	0.49	0.70	0.61	0.51	0.54	0.67
DA	0.03	0.05	0.76	0.03	0.04	0.04
SA	0.21	0.50	0.12	0.61	0.92	0.53

See text for parameter abbreviations.

believe that the missing data biased our results in any way.

A possible explanation of our findings could be the consistent underestimation of the Doppler flow-to-beam angle when calculating velocities transabdominally. It is well known that the velocity calculations are dependent on the cosine of the Doppler beam to true flow angle. There is an increased risk of erronous velocity calculation with increased scanning angles. A small 3° error in the estimation of the angle will cause a 9.2% velocity error at 60° increasing to 29.9% error at 80° (McDicken 1991). It is also well known that blood flow in arteries is complicated (Evans et al. 1991) and may not be laminar or necessarily parallel to the vessel wall. This may be particularly true at the origin of the vessel, after or during a bend in the vessel, at a bifurcation, or in, or distal to, a stenosis. It is therefore quite possible that alignment of the angle correction marker can be inaccurate by 3° or more when estimating the flow-to-beam angle on the B-mode image. As this potential error is a percentage of the velocity, it will be far more noticable at higher velocities. However, the optimal estimated angle for obtaining the Doppler signal from the celiac artery was on average 15°. Therefore, to explain the 20% decrease in the velocities recorded transabdominally at this angle, a consistent angle correction error in the region of 20° would have to be made. Even in the worst-case situation, with an estimated beam-to-flow angle of 35°, the angle correction error would still have to be in the order of 15° (true beam-to-flow angle = 50°). It would also mean that the angle would have to be consistently underestimated to explain the trend toward lower transabdominal velocities. It was, in most cases, also possible to obtain low angles for the origin of the superior mesenteric artery, although reliable angles obtained from samples in the distal superior mesenteric artery and aorta tended to be closer to 60°. There was no significant difference between the optimal angles acquired transabdominally with those acquired intra-abdominally. For these reasons, the angle of insonation is not a sufficient explanation for the significant discrepancy in the trans- and intra-abdominal velocity results.

It has been suggested by some authors that standardising the angle to 60° will result in more reliable results (Rizo et al. 1990; Volteas et al. 1993). Maintaining a constant angle of 60° in all vessels can be difficult, particularly in the celiac artery where attempting deliberately to create an angle of 60° only serves to inject a greater level of uncertainty in the calculation of the velocities. This would only result in increasing the standard deviation for the parameters measured and not in more reliable results.

Another explanation of the observed differences could be related to the instruments. As the same ultrasound machine was used for both trans- and intra-abdominal measurements, cross-instrument variability can be excluded as an explanation for the differences observed. Differing probe frequencies have also been put forward as influencing the velocity results. In our study, a higher probe frequency was used intra-abdominally (7.5 MHz) than transabdominally (3.5 MHz). Basic physics indicates that, although differences in probe frequency produce different Doppler frequency shifts (fd) for the same detected velocity (McDicken 1991), instrument software will take this into account when calculating the velocity. In any event, any error would have manifested itself in a constant manner. In all the velocities recorded, no consistent differences were evident. Therefore, equipment differences cannot explain our results.

Interobserver variability is another possible explanation for our results. Both the trans- and intra-abdomi-

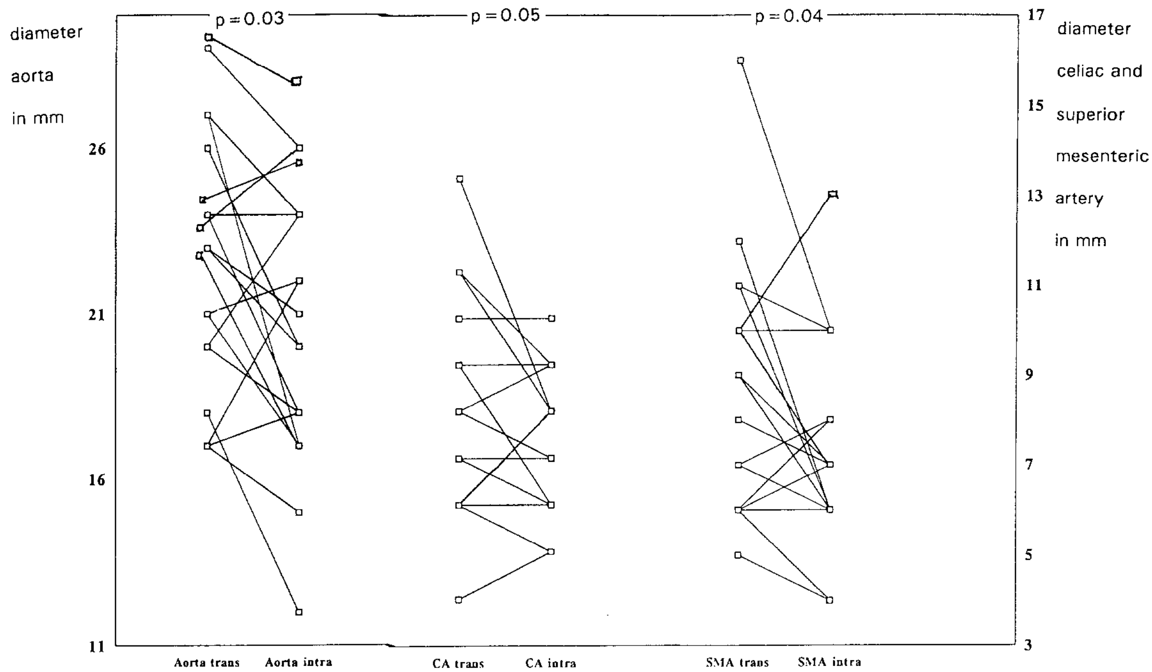

Fig. 1. Trans- and intra-abdominal diameter measurements of the aorta and the celiac and superior mesenteric arteries.

nal results were obtained by different examiners. Both examiners were experienced in duplex examinations of the splanchnic vasculature. Perko and Just (1994) showed that the basic Doppler results did not differ significantly between independent investigators, and we do not believe that this caused the differences recorded in this study.

Theoretically, the laparotomy could also influence the splanchnic circulation. To our knowledge there is no literature supporting this theory; however, cooling-down of the bowel will obviously occur which could result in vasoconstriction, particularly of the superior mesenteric outflow tract. However, we feel that any change in the resistance of the outflow tract would have manifested itself in a significant difference in the resistive and pulsatility indices, which was not the case. It is therefore unlikely that the laparotomy is an explanation for the velocity differences noted in this study.

This study also showed a significant overestimation of the transabdominally measured diameters of the aorta, celiac, splenic, superior mesenteric and inferior mesenteric arteries (Table 3 and Fig. 1). This is probably due to the decreased image quality experienced when scanning transabdominally. The best B-mode image quality is obtained when the area-of-interest is at right angles to the beam; however, the opposite is true when obtaining Doppler signals. All the measurements were taken off the B-mode image at the level of the Doppler sample, when the best flow-to-beam angle was obtained, which is not the best view for obtaining accurate diameter measurements. It is difficult to obtain optimal B-mode visualisation of the origins of the celiac artery and superior and inferior mesenteric arteries as they tend to run parallel to the beam. It may be better not to take the diameter measurement from the same image as the Doppler sample, but to manipulate the probe to obtain a better B-mode image with the vessels lying more at 90° angles to the beam. However, it will then be difficult to be certain that diameter and velocity measurements are taken at the same site, which in turn could lead to inaccurate results. The entire celiac artery is orientated in such a way as to make obtaining the optimal B-mode image for accurate diameter measurements difficult. We therefore believe that diameter measurements of small vessels taken transabdominally, using the same image as that used to obtain the Doppler signal, should be viewed with some scepticism. A reason for measuring the diameter of the vessel is to calculate the flow volume, using the formula: instantaneous flow rate = cross-sectional area × instantaneous average velocity (McDicken 1991). In a vessel with a diameter of 5 mm, an error of 1 mm will cause a 36% error in the area calculation and in a 10 mm diameter vessel it will lead to a 19% area calculation error. Therefore, flow rates calculated using this formula within the splanchnic vasculature will not be reliable. This may in part explain the wide range of volume flow reported in the literature (Geelkerken and van Bockel 1995).

In conclusion, contrary to our expectations, trans- and intra-abdominally obtained splanchnic Doppler velocities are not always equivalent. The standard deviations of the measurements obtained both trans- and intra-abdominally are comparable. The higher velocities recorded in the splanchnic vasculature intra-abdominally, particularly of the celiac artery, cannot be explained sufficiently by Doppler flow angle variation, equipment variation, interobserver variability or laparotomy. The diameter measurements of splanchnic arteries are not accurate enough for the estimation of flow volume calculations when measured transabdominally. Transabdominal duplex sonography is difficult and may not be completely accurate in detecting quantitative flow parameters in the splanchnic arteries. Consequently, biplane angiography remains the gold standard to diagnose splanchnic artery origin stenoses.

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