Feasibility Spectrum for Doppler Flowmetry of Splanchnic Vessels

In Normal and Cirrhotic Populations

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The calculation of absolute blood flow by Doppler flowmetry requires adequate visualization of a vessel in both transverse and longitudinal planes and an insonating angle <60°. The percentage of the splanchnic vessels in a given population in which these criteria could be fulfilled (ie, the feasibility spectrum) is not known. To identify this spectrum in our patient sample, 100 consecutive nonselected patients (58 female, 42 male) and 34 cirrhotics (31 male, three female) were prospectively studied. In addition, from the group of 42 nonselected patients, 31 males with no evidence of liver disease were matched for age, weight, and height with the 31 male cirrhotics. The echo-Doppler feasibility (EDF; success percentage) was determined for the hepatic, superior mesenteric, and splenic arteries and portal, superior mesenteric, and splenic veins. In the nonselected sample, the EDF varied from 86% for the portal vein to 60% for the superior mesenteric artery. In cirrhotics, the EDF ranged from 88% for portal vein to 29% in splenic artery. The total EDF for the nonselected sample (68%) was significantly higher than the EDF for cirrhotics (54%; $P <$ .001). Physical factors (weight, age, height, and sex) affected the EDF in the nonselected patient sample but not in cirrhotics. We conclude that analysis of EDF of splanchnic vessels in these groups clearly demonstrates that the composition of the patient sample has an important bearing on the feasibility spectrum of Doppler study. Female subjects who are thin, young, and short and lighter male patients are better candidates for abdominal Doppler flowmetry. KEY WORDS: splanchnic vessels, blood flow measurements; cirrhosis, ultrasound studies; ultrasound, Doppler studies. *J Ultrasound Med 9:705, 1990)*

Doppler flowmetry, because of its noninvasive nature, has been proposed as a promising method for the clinical study of splanchnic blood flow.[1-4] However, investigators have indicated some concern regarding the reproducibility and accuracy of this method.[5-8]

An important source of variation could be the selection of patients, especially when patients in whom the vessels are not optimally imaged for Doppler measurement are excluded. In fact, Doppler measurements obtained by investigators in a given sample have not always been reproduced in another sample.[9,10] Because studies are performed only in patients in whom Doppler studies are feasible, it seems important that one should study the influence of patient characteristics in a given group on echo-Doppler feasibility (EDF) before interpreting and comparing Doppler flowmetry results from different subjects.

Moreover, the majority of quantitative studies on abdominal vessels with Doppler flowmetry have focused

Received October 24, 1989, from the *Department of Diagnostic Radiology, Yale University, New Haven, Connecticut; †Hepatic Hemodynamic Laboratory, Veteran Affairs Medical Center, Yale University, West Haven, Connecticut; and ¶Veteran Affairs Medical Center, West Haven, Connecticut. Revised manuscript accepted May 24, 1990.

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only on the evaluation of the portal vein.[1,2,6,7,11–13] Little effort has been made to highlight the difficulties and the success rate achieved in other vessels.[3,4,14,15] This prospective study was undertaken to evaluate the feasibility for Doppler flow evaluation in different abdominal vessels in a nonselected sample of patients and in a group of cirrhotic patients. The influence of different physical variables on the feasibility spectrum was determined for each of these groups of patients.

MATERIALS AND METHODS

Equipment

The Doppler equipment used included the Toshiba sonolayer SSA/SSD-100A (Toshiba, Tustin, CA), an Acuson 128 (Acuson, Mountain View, CA), and an ATL Ultramark 8 (ATL, Bothel, WA) duplex systems at frequencies of 2.5 to 5.0 MHz.

Patients

A total of 134 subjects were studied (Table 1). The sample was composed of 100 consecutive nonselected patients referred for an ultrasound examination because of the following reasons: abdominal pain (24), gallbladder disease (21), liver evaluation (12), metastatic disease (nine), abdominal mass (seven), abdominal abscess (seven), pancreatic mass (six), biliary disease (five), hepatoma (three), and miscellaneous (six). Critically ill patients were excluded from the study, but other patients were studied without any selection bias.

The other 34 subjects (31 males and three females) had alcoholic liver cirrhosis. This was documented by liver biopsy in 13 and by clinical data in the remaining patients. Cirrhosis was considered to be alcoholic in origin because alcohol intake in every patient was more than 80 g per day for more than 5 years preceding admission and because other etiologic factors were not evident. The severity of liver disease was assessed according to Child–Turcott's classification: 27 patients belonged to Child's class A, five patients to Child's class B, and two patients to Child's class C.[16]

The group of 31 male cirrhotic subjects were matched for age, weight, and height with the patients chosen from the nonselected sample (the three female cirrhotics were excluded from the analysis of the matched population).

Methods

All subjects fasted on the morning of the ultrasound examination before the Doppler study. After completing the routine ultrasound examination, the purpose of the study was explained to every patient, and an informed consent was obtained. The vascular examination was performed in the supine position, with the head end of the bed elevated by 30°. Different frequencies (2.5 to 5.0 MHz) were used, depending on body habitus, for both imaging and pulse Doppler studies.

Six major vessels of the splanchnic circulation, three arteries and three veins, were studied according to the following protocol: The portal vein (PV) was visualized at the midpoint of the portal trunk, splenic vein (SV) and superior mesenteric veins (SMV) at 2 cm from the confluence, the splenic artery (SA) and hepatic artery (HA) at 2 cm away from the celiac trunk, and superior mesenteric artery (SMA) at 1 cm from the aorta.

Three skilled sonographers, each with more than 4 years of experience, performed the examinations. Because cross-sectional area and a Doppler angle of insonation (angle between the longitudinal vessel scan and the Doppler beam) of less than or equal to 60° are mandatory requirements for absolute blood flow calculations in a vessel (volume = area × mean velocity), these two parameters were evaluated for all vessels.[17,18]

Each vessel was studied for approximately 5 minutes, and the maximum time for completing the protocol was approximately 30 minutes. Each vessel was analyzed and arbitrarily scored from 1 to 4 on the following basis:

1. visible with both the cross-sectional area and a proper Doppler angle of insonation (≤60°);

Table 1: Demographic Profile of the Samples Studied

Groups	Nonselected sample	Cirrhotics sample	Matched nonselected	Matched cirrhotics
Sample size	100	34	31	31
Sex				
Female	58	3	0	0
Male	42	31	31	31
Age (years)	51 ± 2 (14–85)	58 ± 2 (28–76)	57 ± 3 (24–82)	59 ± 2 (28–76)
Body weight (kg)	71 ± 2 (44–148)	81 ± 3 (48–118)	78 ± 3 (46–111)	82 ± 3 (48–118)
Height (cm)	168 ± 1 (147–196)	174 ± 1 (155–193)	174 ± 1 (152–193)	175 ± 1 (155–193)

Values are expressed as mean ± standard error of the mean and as range (in parentheses).

Table 2: Echo-Doppler Feasibility (Percentage Success) for Splanchnic Vessels

		Veins			Arteries			Overall		
Group	No.	PV	SV	SMV	SMA	SA	HA	Veins	Arteries	Total
NS	100	86	69	67	60	61†	64	74†	62†‡	68‡
C	34	88	62	53	41	29†	50	68‡	40‡	54‡
MNS	31	81	42	42	32	36	39	55*	36	45
MC	31	90	61	52	39	26	48	68*	38	53

PV, portal vein; SV, splenic vein; SMV, superior mesenteric vein; SMA, superior mesenteric artery; SA, splenic artery; HA, hepatic artery; NS, nonselected; C, cirrhotic; MNS, matched nonselected; MC, matched cirrhotic.

Chi-square tests: *$P < .05$ (one-tail test); †$P < .01$; ‡$P < .001$.

2. visible with a proper Doppler angle, but not suitable for B-mode cross-sectional area calculation;
3. visible only by B-mode to allow calculation of the cross-sectional area, but not suitable for Doppler measurements; and
4. not visible at all.

Visualization scores of 2, 3, or 4 were failures for an absolute blood flow measurement. Only a score of 1 was considered as a success for Doppler flowmetry. Attainment of the latter score for a vessel was defined as EDF. EDF was determined for each vessel (eg, PV-EDF), for all the three splanchnic veins (vein-EDF), and arteries (artery-EDF) and then for the overall group (eg, the overall-EDF; Table 2). The reasons for failure in EDF were recorded and separately identified as percentages (Table 3).

STATISTICAL ANALYSES

The frequencies of EDF for different vessels were determined for nonselected, cirrhotic, and matched samples. The chi-square test was used to study differences in EDF between various vessels for the two studied samples. The unpaired Student *t*-test was used to analyze differences in sex, age, weight, and height between subjects with success and failure in EDF in the samples under study.

RESULTS

Echo-Doppler Feasibility (Successes)

In the nonselected sample ($n = 100$), the EDF of various vessels varied from 86% for PV to 60% for SMA, with a total-EDF of 68% (Table 2). In 23 of the 32 failures, there was a complete nonvisualization. In the remaining nine failures, either inability to obtain cross-sectional area or to determine velocity led to failure of EDF. The venous EDF was consistently higher than the arterial successes ($P < .01$).

The most frequent cause of failure in PV was obesity, whereas for all other vessels, intestinal gas contributed the highest percentages of failures (Table 3). In cirrhotics, the EDF of different vessels varied from 88% for PV to 29% for SA with a total-EDF of 54%. The vein-EDF was significantly higher than the artery-EDF ($P < .001$), and this was more pronounced in the nonselected sample (Table 2).

When the two samples were compared, the total-EDF of splanchnic vessels in the nonselected sample was significantly higher than in cirrhotics ($P < .001$). However, whereas the artery-EDF was significantly higher in nonselected patients compared with cirrhotics ($P < .001$), the vein-EDF was not significantly different ($P =$ NS).

When the success percentages of the two matched samples were compared, there was a significant differ-

Table 3: Reasons (%) for Failure of Echo-Doppler Feasibility ($n = 100$ Nonselected Patients)

Reasons	PV	SV	SMV	SA	SMA	HA	Overall
Abdominal gas	36	65	78	69	72	57	66
Obesity	64	51	51	46	42	46	48
Poor acoustic window	21	16	18	15	15	19	17
Patient noncooperation	14	3	3	3	2	5	4
Miscellaneous causes	21	19	12	10	10	16	14

Reasons (%) for failure of echo-Doppler feasibility are expressed as a percentage for each vessel. The sum for a given vessel is more than 100% because there could be several reasons for failure in each vessel.

Abbreviations as in Table 2.

Table 4: Physical Characteristics and Echo-Doppler Feasibility (EDF) Influencing the Percentage of Success on EDF in the Nonselected Sample (n = 100).

	Veins			Arteries			Overall	
Vessels	PV	SV	SMV	SMA	SA	HA	Vein	Arteries
Sex								
Females (n = 48)	86	81	81	71	72	74	83	72
Males (n = 52)	83	50	50	43	45	48	61	45
Age								
Younger (≤ 50 years; n = 48)	90	81	81	71	71	75	84	72
Older (>50 years; n = 52)	81	56	56	48	52	52	64	51
Weight								
Lighter (≤69 kg; n = 55)	95	85	84	78	80	80	88	79
Heavier (>69 kg; n = 45)	73	47	49	36	38	42	56	39
Height								
Shorter (≤166 cm; n = 44)	89	80	82	66	70	70	84	69
Taller (>166 cm; n = 56)	82	59	57	54	54	57	66	55
Total	86	69	67	60	61	64	74	62

Percentage of success of EDF with respect to the four physical characteristics when the nonselected sample (n = 100) was divided approximately equally. For example, for the weight variable, the PV-EDF (percentage of success) was 95% in lighter subjects and 73% in heavier subjects.
Abbreviations as in Table 3.

ence for overall vein-EDF in cirrhotics versus matched (P < .05, one-tail test) and the total-EDF was higher in cirrhotics than in the matched sample (Table 2).

EDF and Physical Variables

1) Nonselected Sample (n = 100). The splanchnic vessels were better visualized for Doppler study in females than in males, in lighter (≤ 69 kg) than in heavier subjects, in younger (<50 years) than in older patients, and in shorter (<166 cm) than in taller patients (Table 4). Female sex and weight (Fig. 1) strongly affected the EDF for all the splanchnic vessels.

2) Matched Samples (31 nonselected patients and 31 cirrhotics, all males). There were no significant differences in successes or failures for age, height, and weight in the cirrhotic group. After matching the physical variables with the cirrhotics, the mean weight was significantly different between patients who were suitable or unsuitable for Doppler flowmetry in the nonselected group for all vessels, except PV (Fig. 2).

DISCUSSION

Three factors are likely to have an important bearing on Doppler examination of abdominal vessels, namely, operator skill, the Doppler machine, and the patient sample.

Operator skill is important and could be responsible partly for the variable results reported in different stud-

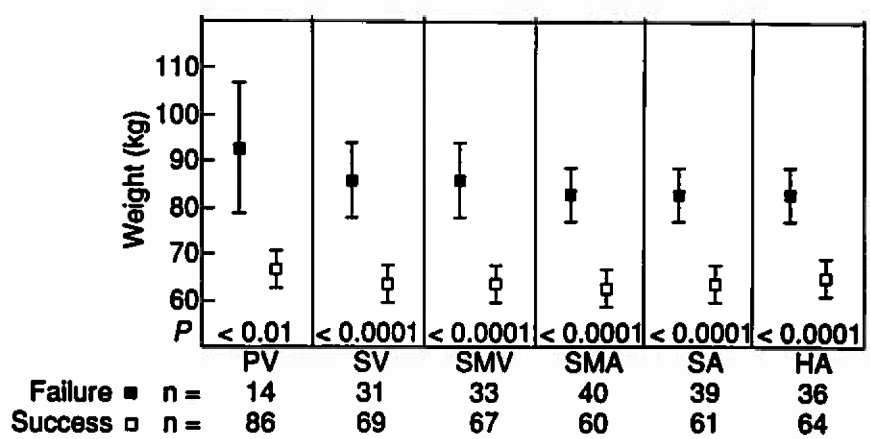

Figure 1 95% confidence limits for weight by success versus failure in the nonselected patients (n = 100). To illustrate, for the portal vein (PV), there were 86 successes and 14 failures. The average weight of the 86 successes was 67 ± 2 kg (mean ± 2 SEM) in contrast to 93 ± 7 kg (mean ± 2 SEM) for the 14 failures. These 95% confidence intervals do not overlap; they are statistically significant at P < .01 level (SV, splenic vein; SMV, superior mesenteric vein; SMA, superior mesenteric artery; SA, splenic artery; HA, hepatic artery).

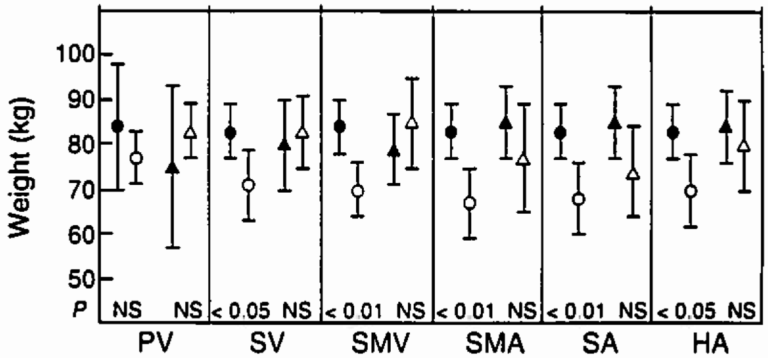

Figure 2 95% confidence limits for weight by success versus failure in the two matched samples (nonselected and matched nonselected [MNS]: failure ●, success O; cirrhotic and matched cirrhotic [MC]: failure ▲, success Δ). Mean weights are expressed as a 95% confidence interval (mean ± 2 SEM) between patients with successes and failures for the six vessels. The statistical evaluation is shown between intragroup failures and successes for MNS and MC. Abbreviations as in Figure 1.

ies.[9] However, with effort and proper training, adequate skills for Doppler examination can be developed. The second factor, the technical limitations of the Doppler machine, may be minimized by selecting an appropriate transducer and by further advances in B-mode imaging and Doppler signal processing. Standardization of Doppler machines will also be required to decrease the variability. The third factor, the patient sample, which cannot be modified, becomes the important source of variability in Doppler measurements.

When a new treatment is shown in controlled trials to improve the prognosis of a particular disease, similar results should be reproducible in a comparable sample.[19] This concept of clinical spectrum is well-accepted when comparing different therapeutic modalities. Unfortunately, it has often been neglected during evaluation of techniques, including Doppler flowmetry. This has led to compilation of conflicting data.

In almost all studies on Doppler measurements, a selected patient sample (eg, cirrhotics) is evaluated and compared with a group of healthy controls.[10,11,15,20] In the present study, we attempted to define the feasibility spectrum for different vessels in separate samples, namely a nonselected group of patients ($n = 100$) and a cirrhotic group of patients ($n = 34$). In addition, for comparative purposes, a sample drawn from the nonselected patients ($n = 31$) was matched with the male cirrhotics ($n = 31$).

It should be emphasized that the nonselected group in this study were not healthy volunteers. They were patients who were referred for an ultrasound examination for specific clinical problems listed earlier. These patients (and not healthy volunteers) are probably closer (than any selected group) to the patients who may require Doppler evaluation in the future. The cirrhotics were studied as an example of a "selected population." The matched sample was specifically analyzed to define the influence of physical variables from the effects of chronic liver disease itself on the EDF of splanchnic vessels.

The criteria for a successful Doppler blood flow measurement are well established, namely, adequate visualization of a vessel in both transverse and longitudinal planes and an insonation angle of $\leq 60°$.[17,18] These criteria defined the EDF of the splanchnic vessels. The results of this study clearly demonstrate the importance of the feasibility spectrum for Doppler flowmetry of abdominal vessels. This spectrum is strongly influenced by different physical determinants as well as the characteristics found in cirrhosis.

In the nonselected group of patients, the success rates for different vessels were influenced by females who were younger, shorter, and lighter, as well as by lighter males, suggesting that young, female, short, and thin individuals are better candidates for abdominal Doppler studies.

When the influence of different physical factors on the EDF of individual splanchnic vessels was analyzed, it became evident that the PV behaves differently from all other vessels. PV-EDF was affected only by body weight. Height, age, and sex had no significant influence on PV-EDF. This could be due to the different acoustic windows used for the visualization of these vessels. The PV is studied through the liver parenchyma. Hence, body habitus becomes the most frequent cause of the EDF-failure. Splanchnic vessels other than the PV are studied in the sagittal and parasagittal planes. Thin, young, short, female subjects and thin males were found to have a higher total-EDF. This is probably due to less retroperitoneal fat and a thinner abdominal wall in these subjects.

The results of this study show that total-EDF in cirrhotic patients was significantly lower than the nonselected sample. This can be explained, in part, by the influence of different physical variables on EDF. More than 90% of our cirrhotics were males, relatively older, and weighed significantly more than the nonselected sample. These characteristics collectively reduced the total-EDF in cirrhotics. On the other hand, the role of an additional factor, portal hypertension, needs to be considered in order to explain similar vein-EDF and a lower artery-EDF between cirrhotics and the nonselected sample. In portal hypertension, the portal venous system is dilated. This probably enhances the vein-EDF in cirrhotics.

The EDF of cirrhotics was also compared with the matched sample to distinguish the influence of physical determinants associated with portal hypertension. It is important to note here that the vein-EDF was higher in the cirrhotics than in the matched sample ($P < .05$, one-tail test). In this situation, this difference in the vein-EDF is probably due only to the dilated portal system, an important intrinsic characteristic of cirrhosis.

Alcoholic cirrhotics represent a relatively homogeneous sample with respect to age, height, and weight. Probably because of this reason, no correlation was seen between physical determinants and EDF. This fact was further supported by the observation that EDF of the matched sample was similar to cirrhotics, but with slight differences that are probably due to the cirrhosis.

Scores from 1 (success) to 4 (failure) were utilized in the evaluation of individual vessels for EDF. While a score of 2 (unsuitable for cross-section measurement), 3 (unsuitable for Doppler measurement), or 4 (unsuitable for both) were all considered to be a failure of EDF, it is worthwhile mentioning that obtaining a score of 2 may be better than obtaining a score of 3. This is because, at times, even without an accurate measurement of the cross-sectional area of the vessel, an indirect blood flow measurement or a relative change in blood flow could be recorded using velocity. This may be particularly true for arteries, in which minimal changes in vessel diameter cannot be determined reliably by the present machines. It may also be useful in measuring venous blood flow in cirrhotics, where the diameter of the already dilated portal system is influenced negligibly by respiration.[21]

In conclusion, this prospective study has defined the feasibility spectrum of Doppler flowmetry in the splanchnic vessels in different patient samples. The concept of a feasibility spectrum serves to indicate the success rate that may be expected from Doppler flowmetry when applied to any given patient group. Awareness of the EDF spectrum of different splanchnic vessels may be helpful in designing and interpreting future studies with Doppler flowmetry.

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