Doppler Sonography Findings Associated with Transjugular Intrahepatic Portosystemic Shunt Malfunction

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OBJECTIVE. Our purpose was to determine the overall accuracy of Doppler sonography and the accuracy of specific Doppler parameters associated with a compromised transjugular intrahepatic portosystemic shunt (TIPS).

MATERIALS AND METHODS. For 43 patients who had undergone TIPS, 64 correlated sonogram–venogram paired examinations were analyzed. Sonographic parameters assessed included absolute velocities plus absolute and percentage changes in velocities measured in the main portal vein (MPV) and in several intrashunt locations (including peak and minimum velocity). Direction of flow and change in direction of flow in the left and right portal veins were also examined. TIPS malfunction was defined as any shunt with greater than or equal to 50% stenosis or any stenosis with a portosystemic gradient greater than 15 mm Hg.

RESULTS. The prospective interpretation of the sonograms using all available parameters resulted in a sensitivity of 92% and a specificity of 72% for detecting TIPS malfunction. Peak shunt velocity (absolute velocity and velocity change), distal shunt velocity, MPV velocity (absolute velocity and percentage change in velocity), change in minimum shunt velocity, and direction of flow in branch portal veins were found to have statistically significant differences between normal and abnormal shunts. Sensitivities for these individual parameters ranged from 64% to 84%, and specificities ranged from 70% to 100%. When either the MPV velocity or the distal shunt velocity was abnormal, the sensitivity was 94%. When both parameters were abnormal, the specificity for detecting TIPS malfunction was 100%.

CONCLUSION. Doppler sonography is a sensitive and relatively specific means of revealing TIPS malfunction. Accuracy depends on analysis of multiple sonographic parameters.

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The transjugular intrahepatic portosystemic shunt (TIPS) has become a widely accepted treatment for the complications of portal hypertension [1, 2]. Shunt or hepatic vein stenosis and shunt occlusion are common short- and intermediate-term complications of the procedure, with 1 year primary patency ranging from 25% to 66% [3–5]. When identified promptly, shunt stenosis or occlusion may be treated before the recurrence of gastrointestinal bleeding or ascites. Revision is usually successful, and the primary-assisted patency of TIPS has been reported to be approximately 85% at 1 year [3–5].

Our institution, like others, has used Doppler sonography as a screening test for patients with a TIPS, both as routine follow-up in asymptomatic patients and in individuals with clinically suspected TIPS malfunction. Definitive sonographic criteria for TIPS stenosis have not been well established in the literature. Recent reports have investigated the role of sonography (particularly Doppler sonography) for the noninvasive detection of TIPS stenosis or occlusion [6–10], but most of these reports have investigated only a few of the potential Doppler sonographic parameters. We initiated this study to establish normal values for Doppler parameters, to determine the sensitivity and specificity for potentially measurable Doppler parameters, and to identify which parameters would be most useful to screen for the malfunctioning TIPS.

Materials and Methods

All 133 patients who underwent the TIPS procedure at our institution between May 1991 and March 1995 were considered for inclusion in the study. Our sonographic screening protocol calls for examinations at 1–3 days, 1 month, 3 months, and 6 months after the TIPS placement and at subsequent 6-month intervals. Patient compliance for

follow-up examinations varied. A patient was included if he or she had a subsequent venogram within 4 weeks of the sonographic examination. For patients with multiple sonogram–venogram paired examinations, we treated each pair as a separate data point. One patient was excluded because he had two parallel shunts. We did not include the immediate post-TIPS sonographic examination as part of our paired sonogram–venogram comparison but instead used this examination as a baseline to compare subsequent examinations against. The sonograms were blindly and prospectively interpreted by reviewing the dictated report; this interpretation represented the radiologists' overall impression of the functional status of the shunt.

Of the 133 patients in our database, 43 patients who underwent a total of 64 paired sonogram and venogram examinations met our selection criteria. In 41 (64%) of 64 cases, the sonographic and venographic examinations were performed within 72 hr of each other, and in 57 (89%) of 64 cases, the paired examinations were within a 2-week span. Patients ranged in age from 24 to 79 years old (mean age, 57) at the time of their TIPS procedure. Sixteen patients were women (37%), and 27 were men (63%).

Patients were examined after an overnight fast. Sonographic examinations were performed in all cases by experienced radiologists using a variety of commercially available equipment and a variety of transducers. They attempted to perform most of the examinations on one unit (Ultramark-9 HDI; ATL, Bothell, WA) to reduce interunit variations. Low-frequency transducers (2–3 MHz) were used most often to accommodate the high velocities in the stents. Power output was set at maximum for all studies. All other Doppler parameters (including pulse repetition frequency, Doppler gain, wall filter, and color priority) varied depending on the patient and the vessel being studied. All velocities were obtained from angle-corrected pulsed Doppler waveforms. In most cases, the Doppler angle was less than or equal to 60°. Velocity measurements made at angles greater than 70° were rejected.

The sonographic parameters studied included main portal vein (MPV) velocity, proximal (the end closest to the portal vein) stent velocity, distal (the end closest to the inferior vena cava) stent velocity, peak stent velocity, minimal stent velocity, the difference between the peak and minimum stent velocity (stent velocity gradient), the ratio of peak to minimum stent velocity (stent velocity ratio), hepatic artery velocity, and hepatic artery resistive index. In addition, we examined the absolute and percentage change of these parameters compared with a baseline (post-TIPS) sonographic examination when one was available. Percentage change was calculated as the current value minus the baseline value divided by the baseline value. The sonogram obtained immediately after the original TIPS placement was used as a baseline for comparison unless the TIPS was revised, in which case the immediate postrevision sonogram served as a new baseline. Left and right portal vein direction was initially classified as antegrade (hepatopetal) or not antegrade (including hepatofugal, bidirectional, nondetectable, and unsure), and we looked at both absolute flow direction and change in flow direction compared with baseline.

Venography was initiated for the following indications: 14 patients (22%) had routine follow-up venography (asymptomatic patients with normal results on sonographic examinations), 39 patients (61%) had venography for evaluation prompted by sonography, seven patients (11%) had rebleeding necessitating venography, and six patients (9%) had venography for other reasons. Two patients had both rebleeding and sonographic abnormality and were counted in both groups. The 14 asymptomatic patients with normal results on sonographic examinations underwent routine venography 6 months after TIPS as part of our early follow-up protocol. Venographic results were classified as abnormal for one of the following criteria: occluded stent, greater than 50% shunt or hepatic vein stenosis, or any shunt or hepatic vein stenosis with a pressure gradient greater than 15 mm Hg. Twenty-five venograms had normal results, and 39 had abnormal results. Of the 39 with abnormal results, six were shunt occlusions and 33 were stenoses of either the shunt or the draining hepatic vein. Not all parameters were available for all patients in the study. For the earlier patients in our group, a less comprehensive sonographic protocol was used, and as our clinical experience grew, more parameters were routinely evaluated in each sonographic examination for each patient. The following is a list of representative parameters and the frequency with which they were measured in our series: peak shunt velocity (100%), MPV velocity (95%), multiple (two or more) shunt velocities (91%), peak shunt velocity with baseline comparison (80%), MPV velocity with baseline comparison (67%), hepatic artery velocity and resistive index (61%), and hepatic artery velocity and resistive index with baseline comparison (31%).

Most outcome variables were continuous. *T* tests were used to analyze these variables; however, the primary method of analysis involved converting continuous data into binary diagnostic decisions by examining frequency distributions for those with normal and abnormal venograms and determining cutoff points. These binary variables and the categoric sonography variables were examined for association with venographic results using contingency tables and tested for statistical significance with the chi-square test.

After the initial analysis, the statistically significant predictors were used in a logistic regression model to determine which remained powerful predictors in the presence of others. First, the parameters were grouped into families that addressed different aspects of the same measurement (e.g., MPV velocity, change in MPV velocity, and percent change in MPV velocity). The parameters within a family were tested against each other by using them as predictors in a logistic regression model. The strongest specific measures within each family were then combined in a model in a backward stepwise regression.

Results

In the study cohort, the Child class was A in six patients (14%), B in 22 (51%), and C in 15 (35%). In 40 patients, TIPS were created using 10-mm stents, and in three patients 12-mm stents were used. The demographic variables (age, sex, Child class, and stent size) did not correlate with the presence or absence of venographic abnormalities in our patient population (Table 1).

Patients with abnormal venographic results had a mean MPV velocity of 27.5 cm/sec, whereas patients with normal venographic results had a mean MPV velocity of 42.8 cm/sec ($p = .012$ using the *t* test). The results of the chi-square test using 30 cm/sec as a possible cutoff value were highly significant ($p < .001$). At less than 30 cm/sec, five venographic results were normal and 31 were abnormal. At greater than or equal to 30 cm/sec, 17 venographic results were normal and seven were abnormal. Percentage change in MPV velocity also related significantly to abnormal results on venography. Patients who had abnormal venographic results had a mean percentage change in MPV velocity of –36% (±26% SD), whereas patients who had normal venographic results had a mean percentage change in MPV velocity of –1% (±40% SD). Using a 20% decline in MPV velocity when compared with baseline as a cutoff value, the sensitivity and specificity of this test were 78% and 75%, respectively.

After studying the distribution of the peak velocities of the shunts in both the population with normal results and the population with abnormal results (Fig. 1), the range of 90–189 cm/sec was chosen as the spread over which patients were most likely to have normal results (normal range). Within this range, 18 venographic results were normal and seven were abnormal. Outside this range, seven were normal and 32 were abnormal ($p < .001$ using the chi-square test). The sensitivity and

TABLE 1 Demographic Characteristics in Patients with Normal and Abnormal Venograms

Demographic Characteristic	Venogram Result	
	Normal	Abnormal
Mean age (yr)	57	57
Male sex	16 (64%)	25 (64%)
Female sex	9 (36%)	14 (36%)
Child class A	5 (20%)	4 (10%)
Child class B	10 (40%)	21 (54%)
Child class C	10 (40%)	14 (36%)

specificity were 84% and 70%, respectively. We also reexamined the data using as the normal range a 100–200 cm/sec spread, which had slightly lower sensitivity and specificity, 79% and 68%, respectively.

The relationship was also significant between the change in peak stent velocity compared with a baseline examination and abnormal venographic results. Looking at the frequency distribution of the peak velocity changes for both normal and abnormal venographic results, we tested several ranges to select the best possible normal range. A drop in peak stent velocity of less than or equal to 40 cm/sec or a rise of less than 60 cm/sec was found to be the best normal range, producing 16 normal venographic results and eight abnormal. Outside this range, three venographic results were normal and 24 were abnormal ($p < .001$ using the chi-square test). The sensitivity and specificity for these criteria were 75% and 84%, respectively.

The distal shunt velocity was also analyzed by examining the frequency distribution of both normal and abnormal venographic results, and various normal ranges were tested in a fashion similar to that for the peak shunt velocity. Within the range of 90–219 cm/sec, 17 of 28 patients had normal results at venography (negative predictive value of 61%), and outside this range, 22 out of 25 patients had abnormal results at venography (positive predictive value of 88%) ($p = .003$ using the chi-square test). Within this normal range, the sensitivity was 67% and the specificity was 85%. The degree of change in the distal shunt velocity also correlated with abnormal venographic results. When the distal shunt velocity increased greater than 50 cm/sec or decreased by more than 40 cm/sec, the venographic result was abnormal in 13 of 14 patients (positive predictive value of 93%). However, when the change was within this range, eight of 14 patients had normal results at venography (negative predictive value of 57%). This relationship was also statistically significant ($p = .005$ using the chi-square test).

We examined the velocity gradient across the TIPS shunt (as calculated by the peak stent velocity minus the minimum velocity measured). In the total patient population, no gradient combined adequate sensitivity and specificity. When the most recent 25 correlative studies from nonoccluded shunts were analyzed, a velocity gradient of 100 cm/sec was found to have a sensitivity of 56% (9/16), a specificity of 78% (7/9), a positive predictive value of 82% (9/11), and a negative predictive value of 50% (7/14). Only one patient in this group had a gradient between 50 and 100 cm/sec. Therefore, our results were almost identical using a velocity gradient of 50 cm/sec as the upper limit of normal.

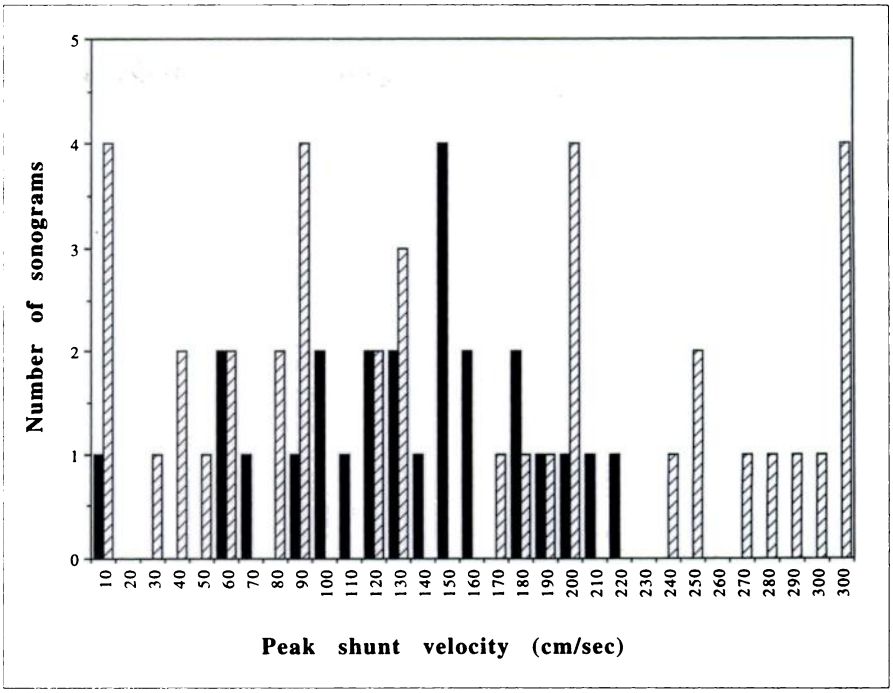

Fig. 1.—Bar graph shows distribution of peak shunt velocities in both normal (black) and abnormal (shaded) venogram populations.

Although the trend was for patients with normal venographic results to have higher minimum shunt velocities (mean, 95.4 cm/sec) than patients with abnormal venographic results (72.3 cm/sec), this trend was not statistically significant ($p = .067$ using the t test). All 16 patients who showed a decrease of 30 cm/sec or more in the minimum shunt velocity when compared with baseline had abnormal venographic results (positive predictive value of 100%). However, eight of 24 patients who had abnormal venograms had a decrease (or change) in the minimum shunt velocity of less than 30 cm/sec. The sensitivity and specificity for this parameter were 67% and 100%, respectively. The percentage change in minimal velocity showed a similar trend, with a drop of 30% or more as the best cutoff value (sensitivity, 71%; specificity, 78%).

The direction of portal vein flow was categorized as antegrade or not antegrade, and the left and right portal veins were evaluated separately. In the right portal vein, flow was not antegrade for 23 normal venographic results and 22 abnormal venographic results, and flow was antegrade for two normal venographic results and 17 abnormal venographic results ($p = .002$ using the chi-square test). In the left portal vein, flow was not antegrade for 23 normal venographic results and 18 abnormal venographic results, and flow was antegrade for two normal venographic results and 21 abnormal venographic results ($p < .001$ using the chi-square test). In addition, we examined the relationship between abnormal venographic results and antegrade flow in either portal vein. Flow was not antegrade for 20 normal venographic results and 14 abnormal venographic results, and flow was antegrade for four normal venographic results and 25 abnormal venographic results ($p = .002$ using the chi-square test).

Investigation of changes in the direction of branch portal vein flow revealed that a change from retrograde to antegrade flow in the left portal vein was seen in 12 patients with abnormal venographic results and one patient with normal venographic results ($p = .009$ using the chi-square test). A change from retrograde to antegrade flow in the right portal vein was seen in six patients with abnormal venographic results and one patient with normal venographic results ($p = .155$ using the chi-square test). Most of the cases in which conversion of retrograde flow to antegrade flow preceded an abnormal venography result occurred early in our study.

Only one case occurred in our last 25 sonogram–venogram correlations.

The other variables examined failed to show a pattern or trend to suggest that they would be useful as screening parameters for sonography. These variables included the proximal shunt velocity, the hepatic artery velocity, the hepatic artery resistive index, and the peak velocity divided by the minimum velocity. Likewise, changes or percentage changes of these factors when compared with baseline showed no relationship to suggest their usefulness in identifying patients with TIPS malfunction.

The logistic regression identified two significant independent variables as predictors for abnormal venographic results: the MPV velocity (<30 cm/sec as abnormal; $p = .002$ using the chi-square test) and the distal shunt velocity (<90 cm/sec and ≥220 cm/sec as abnormal; $p = .007$ using the chi-square test), both with an odds ratio of 12.9. Considering a model in which either of these parameters is abnormal, the sensitivity and specificity were 94% and 72%, respectively, for predicting shunt malfunction, and with both abnormal, the sensitivity and specificity were 55% and 100%, respectively.

Although the appropriate normal and abnormal values for these various parameters were not well understood at the time that the sonograms were performed, the overall prospective impression of the radiologist who interpreted the examinations was accurate (Table 2). The overall sensitivity and specificity in determining the functional status of the shunt were 92% and 72%, respectively.

Discussion

A wide variety of post-TIPS follow-up imaging protocols use combinations of sonography and venography. The ideal screening technique for a malfunctioning TIPS would be inexpensive, noninvasive, and accurate. Although a cost–benefit analysis comparing sonography with venography is beyond the scope of this study, sonography has the potential to be the better screening test. Many potential sonographic parameters can be used to evaluate the status of a TIPS shunt; no consensus exists on the optimal sonographic screening protocol. Our study is unique because we have prospectively looked at a large number of sonographic parameters in a blinded fashion and have determined normal and abnormal values for these parameters and their resulting sensitivity, specificity, and positive and negative predictive values. These results are summarized in Table 2. The logistic regression analysis is most useful to confirm the findings of the univariate analysis but did not offer any significant additional insight.

The parameter that has received the most attention to date is the peak shunt velocity. Daniel et al. [11] reported that a direct correlation does not exist between the peak shunt velocity and the portosystemic gradient. More commonly, however, investigators have attempted to establish a lower limit of normal for shunt velocity. This limit is based on the assumption that a hemodynamically significant stenosis will decrease flow through the stent and cause reduced velocity in the nonstenotic portions of the stent. Chong et al. [8] determined that 50 cm/sec was a reliable cutoff value to separate patients with and without shunt stenosis. Using this value, Chong et al. had a sensitivity of 100% and a specificity of 93%. Unfortunately, this series included only eight cases of shunt stenosis. A similar result was obtained by Foshager et al. [7], who suggested that 60 cm/sec be used as the cutoff value. Again, this study was limited by a relatively small number (10) of stenotic shunts. Yet only one of 15 patients with shunt stenosis had a peak velocity below 60 cm/sec (sensitivity, 7%) in the study by Dodd et al [6]. Our data, based on a series that includes 33 stenotic shunts, would also indicate that 50–60 cm/sec is too low a value to use to detect shunt stenosis. On the basis of our results, we suggest that the lower limits of normal for peak shunt velocity is 90 cm/sec.

Another approach to peak shunt velocities is to establish an upper limit for normal, assuming that a focal stenosis would cause an elevated velocity at the level of stenosis. Previous reports that have looked at shunts in asymptomatic patients (not necessarily patients with venographic proof of normality) have shown an upper limit for normal from 185 cm/sec to 220 cm/sec [9,10]. Foshager et al. [7] recently showed that the upper limit for normal decreases with time. In their series the upper limit at 6 and 12 months was 200 cm/sec. This value is similar to the value of 190 cm/sec that we determined from our series.

A potential method of evaluating shunt velocities that has not been formally studied to date is to compare the maximum velocity in the shunt to the minimum velocity. The difference between these values will theoretically increase in the presence of a focal stenosis. Dodd et al. [6] allude to this theory in their paper and suggest that a difference of 50 cm/sec or greater be used as a cutoff. The accuracy of this parameter is something that they are now evaluating prospectively. Our data from the most recent 25 correlative studies showed that patients with velocity gradients greater than 100 cm/sec were more likely to have a stenosis (positive predictive value of 82%). Unfortunately, many patients with a stenosis did not have such a high gradient (sensitivity of 56%). The low sensitivity is not unexpected, because accurately determining both a maximum and a minimum velocity is necessary to determine an accurate gradient. In addition, a diffuse stenosis might not result in an abnormal gradient. On the other hand, when the maximum and minimum velocities are accurately determined, it is logical that an abnormal gradient would be highly predictive of a stenosis. Interestingly, our results were almost identical whether we used 100 or 50 cm/sec as our upper limit of normal for the velocity gradient. Therefore, our data do not clearly reveal which cutoff value is best.

Temporal changes in peak shunt velocity have been addressed by Dodd et al. [6], who found that changes (both increases and decreases) of greater than 50 cm/sec were 93% sensitive and 77% specific for the detection of stenosis. Our results were similar, showing that a decrease of greater than 40 cm/sec or an increase of greater than 60 cm/sec predicted an abnormal venographic result. However, our sensitivity (75%) was lower, and our specificity (84%) was slightly higher.

As at other centers, our protocol for evaluating TIPS has evolved as we have gained experience with these sonographic examinations. In our early experience we did not attempt to evaluate the entire shunt and usually did not obtain waveforms from the stenotic segment of abnormal shunts. Therefore, stenotic shunts usually manifested as decreased shunt velocities. In our more recent experience we have become more successful in identifying and sampling the stenotic segment of the shunt, and thus, stenosed shunts are often manifested by elevated peak shunt velocities. To analyze the sensitivity of shunt velocity in this entire group of patients, we have elected to consider a shunt stenosed if peak velocities fall either below or above the normal range (90–189 cm/sec). Using this approach, we obtained a sensitivity of 82% and a specificity of 72%.

Another parameter that has received some attention is the MPV velocity. As expected, the MPV velocity increases after placement of a TIPS, and many studies have docu-

TABLE 2 Suggested Doppler Sonography Criteria for Transjugular Intrahepatic Portosystemic Shunt Malfunction

Criterion	Velocity (cm/sec) or Direction	Sensitivity (%)	Specificity (%)	Positive Predictive Value (%)	Negative Predictive Value (%)
Peak shunt velocity	<90 or ≥190	84	70	82	72
Change in peak shunt velocity	Decrease >40 Increase ≥60	71	88	89	67
Distal shunt velocity	<90 or ≥220	67	85	88	61
Main portal vein velocity	<30	82	77	86	71
Flow in left or right portal vein	Antegrade	64	83	86	59
Overall Impression	Not applicable	92	72	84	86

mented a statistically significant difference. The mean MPV velocity following TIPS was 41 ± 13 cm/sec and 41.5 ± 18.5 cm/sec, respectively, in the series of Foshager et al. and Surratt et al. [7, 10]. These values are similar to our current value of 42.8 cm/sec. Other series have determined MPV velocities in normally functioning shunts but have not determined the accuracy of this parameter in detecting shunt malfunction. In our current series, a cutoff value of 30 cm/sec for the MPV velocity resulted in an 82% sensitivity and a 77% specificity, and the logistic regression analysis supports the usefulness of this parameter. Temporal changes in MPV velocity have been studied by Zemel et al. [12]. They reported a positive predictive value of 100% using a decrease of greater than 33% from baseline as their cutoff value. They did not describe the sensitivity of this parameter. Using a 20% decrease in MPV velocity as our cutoff, we obtained a sensitivity of 78% and a specificity of 75%. Using a 33% cutoff value, we would have seen our sensitivity drop to 67% and our specificity remain the same (75%).

As a compensatory response to decreased portal perfusion of the liver, hepatic artery flow increases after the TIPS procedure. Foshager et al. [7] have documented a statistically significant change in hepatic artery velocity following TIPS. In their study, the mean peak systolic hepatic artery velocity was 79 cm/sec before TIPS placement and 131 cm/sec after placement. Although they did not report on this parameter, they speculated that temporal decreases in hepatic artery velocity may be a secondary sign of shunt dysfunction and actually made this observation in a few isolated cases. We agree that this parameter has theoretic value, but our series did not show a statistically significant difference in hepatic artery velocities or resistive indexes between normally and abnormally functioning shunts. This finding is most likely due to limitations in the ability to obtain reproducible readings from the hepatic arterial system using Doppler techniques.

Investigation of flow direction in the right and left portal veins has been reported previously. Surratt et al. [10] and Longo et al. [9] originally showed that reversed (hepatofugal) flow develops in the right or left portal vein in most patients following TIPS. Surratt et al. and Foshager et al. [7] described cases in which shunt stenosis was associated with a conversion of flow from retrograde to antegrade in the right or left portal vein. However, the number of cases in which this parameter was studied was too low for significant conclusions to be drawn from either of these studies. In our study, we could show a statistically significant difference in the direction of right and left portal venous flow in normal versus abnormal shunts ($p = .002$). Twenty-five of 29 patients with antegrade flow in either the right or the left portal vein had abnormal venographic results (positive predictive value of 86%). Unfortunately, only 20 of 34 patients with nonantegrade flow had normal venographic results (negative predictive value of 59%). We also found that a temporal change in flow direction from retrograde to antegrade was a strong indication of shunt malfunction (positive predictive value of 92% on the left and 86% on the right) but overall was an insensitive parameter (15–31%). We now believe that conversion of left and right portal vein flow from retrograde to antegrade is a late sign of TIPS malfunction. Our more recent experience suggests that through measurement of shunt and MPV velocities, detecting shunt malfunction before a change in portal vein branch flow is possible.

The final parameter we analyzed was the blinded, prospective, overall interpretation of the sonographic examinations by the physician performing the examination. When compared with venography, the sensitivity and specificity of sonography in detecting shunt malfunction were 92% and 72%, respectively. These results are better than the results of any individual sonographic parameter because the prospective interpretation was based on information from all the parameters that were available at the time of the examination. In addition, other findings that were not analyzed in this study, such as actual visualization of intimal hyperplasia or hepatic vein stenosis on color Doppler sonography, assisted in the prospective interpretation.

The reader should realize that not all sonograms with normal results (from our overall clinical experience) were followed by a correlative venogram and thus were not included in this study. Assuming that some of the unanalyzed sonograms that had normal results were actually falsely negative, the sensitivity of sonography (defined as true positives / [true positives + false negatives]) may be slightly lower than we determined. Conversely, the specificity (defined as true negatives / [true negatives + false positives]) that we determined may be artifactually low because none of these unanalyzed normal cases were included in the total number of true negatives.

In summary, we have shown that Doppler sonography is a sensitive and relatively specific way to detect TIPS malfunction, particularly when multiple parameters are examined. Achieving high sensitivity is optimal so that malfunctioning shunts can be identified and shunt revision performed before symptomatic deterioration. In our experience, MPV velocity and peak shunt velocity are the individual Doppler parameters that provide the highest sensitivity. The prospective, blinded interpretation of the examination by the sonographer is the most sensitive overall criterion (92%).

References

1. Coldwell DM, Ring EJ, Rees CR, et al. Multicenter investigation of the role of transjugular intrahepatic portosystemic shunt in management of portal hypertension. *Radiology* **1995**;196:335–340
2. Kerlan RK, LaBerge JM, Gordon RL, Ring EJ. Transjugular intrahepatic portosystemic shunts: current status. *AJR* **1995**;164:1059–1066
3. LaBerge JM, Ring EJ, Gordon RL, et al. Creation of transjugular intrahepatic portosystemic shunts with the Wallstent endoprosthesis: results in 100 patients. *Radiology* **1993**;187:413–420
4. Haskal ZJ, Pentecost MJ, Soulen MC, Shlansky-Goldberg RD, Baum RA, Cope C. Transjugular intrahepatic portosystemic shunt stenosis and revision. *AJR* **1994**;163:439–444
5. Lind CD, Malisch TW, Chong WK, et al. Incidence of shunt occlusion or stenosis following transjugular intrahepatic portosystemic shunt placement. *Gastroenterology* **1994**;106:1277–1283
6. Dodd GD, Zajko AB, Orons PD, Martin MS, Eichner LS, Santaguida LA. Detection of transjugular intrahepatic portosystemic shunt dysfunction: value of duplex Doppler sonography. *AJR* **1995**;164:1119–1124
7. Foshager MC, Ferral H, Nazarian GK, Castanada-Zuniga WR, Letourneau JG. Duplex sonography after transjugular intrahepatic portosystemic shunt (TIPS): normal hemodynamic findings and efficacy in predicting shunt patency and stenosis. *AJR* **1995**;165:1–7
8. Chong WK, Malisch TA, Mazer MJ, Lind CD, Worrell JA, Richards WO. Transjugular intrahepatic portosystemic shunt: US assessment with maximum flow velocity. *Radiology* **1993**;189:789–793
9. Longo JM, Bilbao JI, Rousseau HP, et al. Transjugular intrahepatic portosystemic shunt: evaluation with Doppler sonography. *Radiology* **1993**; 186:529–534
10. Surratt RS, Middleton WD, Darcy MD, Melson GL, Brink JA. Morphologic and hemodynamic findings at sonography before and after creation of a transjugular intrahepatic portosystemic shunt. *AJR* **1993**;160:627–630
11. Daniel BL, Rubin JM, Fowlkes JB, Williams DM, Adler RS. The hemodynamics of transjugular intrahepatic portosystemic shunts: investigations with Doppler sonography and development of an in vitro model. *Acad Radiol* **1996**;3:455–462
12. Zemel G, Katzen BT, Grubbs GE, Moore BS, Benenati JF, Becker GJ. Sonographic indicators of unsuccessful transjugular intrahepatic portosystemic shunts (abstr). *Radiology* **1994**;193(P):167