Doppler Sonography of the Inferior and Superior Mesenteric Arteries in Ulcerative Colitis

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ABSTRACT: *Purpose.* The purpose of this study was to evaluate the Doppler sonographic blood-flow parameters and spectral patterns in the inferior mesenteric artery (IMA) and superior mesenteric artery (SMA) in patients with active and inactive (remission-phase) ulcerative colitis (UC).

Methods. The IMAs and SMAs of 25 patients with active-phase UC (group 1), 19 patients with remission-phase UC (group 2), and 22 healthy, asymptomatic subjects (control group) were evaluated by duplex Doppler sonography. The 25 patients in group 1 were categorized into 2 subgroups on the basis of the extent of disease as determined by double-contrast barium enema x-ray study and colonoscopy. The first subgroup (group 1a) consisted of 11 patients with active involvement of the left colon from the rectum to the splenic flexure. The second subgroup (group 1b) consisted of 14 patients with active involvement of the entire colon. The peak systolic velocity (PSV), end-diastolic velocity (EDV), mean velocity (Vmean), resistance index (RI), and pulsatility index (PI) were determined from the Doppler spectral analysis. The inner diameter and cross-sectional area of the IMA and SMA were measured, and the blood-flow volume was calculated. The results were compared between the patient groups and control subjects.

Results. In the IMA, the mean blood-flow volume, mean PSV, mean EDV, and Vmean were significantly higher, the mean PI was significantly lower, and the mean diameter and the mean cross-sectional area were significantly larger in group 1 than in group 2 or in the control group ($p < 0.001$). The mean PSV and the Vmean of the IMA were significantly higher in group 1a than in group 1b ($p < 0.05$). The mean blood-flow parameters in the SMA were not significantly different between groups 1 and 2 or between either group 1 or group 2 and the control subjects. The mean EDV in the SMA was significantly higher and the mean PI and the mean RI were significantly lower in group 1b than in group 1a ($p < 0.01$).

Conclusions. Duplex Doppler sonography of the IMA and SMA can be used to evaluate inflammatory disease of the large bowel, to assess disease extent, and to document response to therapy. © 2001 John Wiley & Sons, Inc. *J Clin Ultrasound* **29**:130–139, 2001.

Keywords: Doppler ultrasonography; inferior mesenteric artery; superior mesenteric artery; ulcerative colitis

Ulcerative colitis (UC) is a chronic intestinal disease characterized by inflammation of unknown etiology. In the active (acute) phase of UC, 10–15% of patients require immediate hospitalization to prevent or treat complications, such as hypokalemia, toxic megacolon, shock, or colonic perforation. Clinically, UC shows frequent exacerbations and remissions.[1] Radiologic or endoscopic examinations are frequently repeated during exacerbations to define the distribution, extent, and severity of disease.

Doppler sonography is a noninvasive method that has the potential to dynamically evaluate the mesenteric blood flow in patients with UC, especially during exacerbations. Reports have generally focused on Doppler sonographic findings in the superior mesenteric artery (SMA) in patients with Crohn's disease[2–4] and UC.[5,6] Doppler sono-

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graphic studies of the inferior mesenteric artery (IMA) in cases of inflammation of the large bowel are rare.[7]

The aim of this study was to evaluate the Doppler sonographic blood-flow parameters and spectral patterns in the IMA and SMA in patients with active and inactive (remission-phase) UC.

PATIENTS AND METHODS

Between January 1999 and January 2000, the IMAs and SMAs of 40 consecutive patients with a suspicion of UC admitted from the Department of Gastroenterology to the Department of Radiology for double-contrast barium enema x-ray study were evaluated. One radiologist performed duplex Doppler sonography in each case before the barium enema study. All patients provided oral informed consent.

In 25 of the 40 patients, the findings of the double-contrast barium enema study of the large bowel demonstrated UC, which was confirmed by colonoscopy and then by biopsy. In 15 subjects whose symptoms suggested large-bowel disease, the barium enema revealed no apparent large-bowel abnormality. The 25 patients with active UC constituted group 1; there were 9 women and 16 men, with an age range of 28–71 years [mean ± standard deviation (SD), 46 ± 12 years]. The extent of disease in the patients in group 1 was evaluated by the double-contrast barium enema study of the large bowel and by colonoscopy. The patients were divided into 2 subgroups on the basis of the extent of the disease. The first subgroup (group 1a) consisted of 11 patients (3 women and 8 men), with an age range of 29–61 years (mean ± SD, 47 ± 10 years). The patients in group 1a had active disease affecting the left colon from the rectum to the splenic flexure. The second subgroup (group 1b) consisted of 14 patients (6 women and 8 men), with an age range of 28–71 years (mean ± SD, 45 ± 13 years). The patients in group 1b had active disease affecting the entire colon. There was no patient with isolated right-colon involvement in our study.

During the same period, the IMAs and SMAs of 19 patients who were clinically in the remission phase of previously diagnosed UC (group 2) were also evaluated with duplex Doppler sonography. Group 2 had 9 men and 10 women, with an age range of 24–55 years (mean ± SD, 41 ± 9 years).

A control group of 22 healthy, asymptomatic subjects without any history of cardiovascular or intestinal disease underwent duplex Doppler sonography. The control group consisted of 12 women and 10 men, with an age range of 23–75 years (mean ± SD, 42 ± 11 years) and were recruited from the investigators' office staff and their families.

Duplex Doppler sonography was performed with a model 128XP/4 ultrasound scanner (Acuson, Mountain View, CA) and 3.5-MHz convex-array and 7-MHz linear-array transducers. All patients and control subjects were examined in the morning in resting conditions after overnight fasting (range, 9–16 hours), with the subject in a supine position. Adjusting the angle of insonation precisely was crucial to measurement accuracy.[8] The accuracy of a velocity estimate obtained with Doppler sonography is only as great as the accuracy of the measurements of the Doppler angle. This is particularly true as the Doppler angle exceeds 60°. In general, the Doppler angle is best kept at 60° or less because a small change in the Doppler angle above 60° results in significant inaccuracy in the calculated velocity. Angle-corrected Doppler signals were obtained from the proximal 4 cm of the SMA and the proximal 3 cm of the IMA. The Doppler angle was kept smaller than 60°. The wall filter was set as low as possible to detect slow diastolic flow. The pulse-repetition frequency was set according to the flow velocity to avoid aliasing. The sample volume was adjusted to encompass as much of the bowel lumen as possible without including the wall. The patients were instructed to suspend respiration during Doppler recordings.

After an initial survey of the abdomen to rule out any occlusive or stenotic abnormality in the aorta and its main branches, the IMA and SMA were identified by B-mode sonography. The IMA originates from the left anterior wall of the abdominal aorta, at approximately the level of the third lumbar vertebra. It courses downward on the left side of the aorta. It is practical to search for the origin of the IMA at a distance of 3–5 cm from the aortic bifurcation. The small caliber of the IMA, its deep location in the abdomen, and gas in the overlying intestine render sonographic depiction of this vessel difficult. Color Doppler sonography was used if the IMA could not be visualized by B-mode sonography. This was necessary in 6 of 22 control subjects because of obesity and overlying bowel gas. Because most of our patients were not obese, the IMA and SMA were located easily. Accordingly, it took about 50 minutes to perform each Doppler sonographic evaluation of both the IMA and SMA.

To analyze the Doppler signals, the peak systolic velocity (PSV) and end-diastolic velocity

(EDV) were measured, and a spectral trace of the waveform was obtained. The resistance index (RI), pulsatility index (PI), and mean velocity (Vmean) were calculated automatically by the spectral analyzer of the ultrasound system. At the site of Doppler interrogation, the inner diameters of the IMA and SMA were measured on gray-scale images, and the cross-sectional area was determined by the built-in software. Three diameter measurements were taken in each subject and were averaged. Blood-flow volume (BFV) (in ml/minute) was calculated using the formula: Vmean (in m/second) × cross-sectional area (in mm^2) × 60. The Doppler findings were compared between the patient groups and between each patient group and the control subjects. To assess the efficacy of therapy, we also evaluated the IMA and SMA Doppler blood-flow parameters and spectral patterns in 6 patients in group 1 (4 with left-colon involvement and 2 with entire-colon involvement) approximately 14 days (range, 10–20 days) after the start of therapy, when these patients became free of symptoms.

The results were reported as means ± SDs. The Mann-Whitney U–Wilcoxon rank sum W test was used to evaluate the differences in the mean diameter and area of the IMA and in the mean area and BFV of the SMA between the patient groups and the control group, as well as differences in the mean PSV of the IMA and in the mean diameter, area, and BFV of the SMA between groups 1a and 1b. The differences between the mean values of the remaining Doppler parameters were compared using the Student's t-test. A p value of less than 0.05 was considered statistically significant.

RESULTS

The Doppler parameters of the IMAs and SMAs in groups 1 and 2 and in the control group are shown in Table 1.

In the IMA, the mean BFV, mean PSV, Vmean, and mean EDV were significantly higher in group 1 (507 ± 180 ml/minute, 1.72 ± 0.47 m/second, 0.54 ± 0.11 m/second, and 0.22 ± 0.05 m/second, respectively) than in the control group (95 ± 44 ml/minute, 0.98 ± 0.28 m/second, 0.25 ± 0.07 m/second, and 0.08 ± 0.03 m/second, respectively) ($p < 0.001$) and were significantly higher in group 1 than in group 2 (134 ± 43 ml/minute, 1.00 ± 0.24 m/second, 0.25 ± 0.06 m/second, and 0.11 ± 0.03 m/second, respectively) ($p < 0.001$). The mean PI in the IMA was significantly lower in group 1 (2.76 ± 0.57) than in the control group (3.57 ± 0.91) ($p < 0.001$) and was significantly lower in group 1 than in group 2 (3.60 ± 0.84) ($p < 0.001$). The mean RI of the IMA in patients in group 1 (0.86 ± 0.04) was not significantly different from that in the control group (0.90 ± 0.06) or that in group 2 (0.88 ± 0.03). The mean diameter and cross-sectional area of the IMA in group 1 (4.4 ± 0.5 mm and 15 ± 3 mm^2, respectively) were significantly larger than in the control group (2.9 ± 0.4 mm and 6 ± 2 mm^2, respectively) ($p < 0.001$) and were significantly larger than in group 2 (3.3 ± 0.4 mm and 9 ± 2 mm^2, respectively) ($p < 0.001$). There were no significant differences in the mean Doppler parameters of the IMA between the control group and group 2.

The Vmean in the IMA was significantly higher in group 1a (0.60 ± 0.09 m/second) than in

TABLE 1
Doppler Parameters of Inferior and Superior Mesenteric Arteries in Patients with Active Ulcerative Colitis (Group 1) Affecting the Left Colon (Group 1a) or the Entire Colon (Group 1b), in Patients with Inactive Ulcerative Colitis (Group 2), and in the Control Group

Group	Mean EDV, m/second	Vmean, m/second	Mean PSV, m/second	Mean RI	Mean PI	Mean Diameter, mm	Mean Cross-Sectional Area, mm^2	Mean BFV, ml/minute
Inferior Mesenteric Artery								
1 (n = 25)	0.22 ± 0.05	0.54 ± 0.11	1.72 ± 0.47	0.86 ± 0.04	2.76 ± 0.57	4.4 ± 0.5	15 ± 3	507 ± 180
1a (n = 11)	0.24 ± 0.04	0.60 ± 0.09	1.92 ± 0.37	0.86 ± 0.03	2.80 ± 0.60	4.5 ± 0.5	16 ± 3	572 ± 173
1b (n = 14)	0.21 ± 0.06	0.49 ± 0.11	1.56 ± 0.50	0.86 ± 0.05	2.74 ± 0.57	4.4 ± 0.5	15 ± 3	456 ± 173
2 (n = 19)	0.11 ± 0.03	0.25 ± 0.06	1.00 ± 0.24	0.88 ± 0.03	3.60 ± 0.84	3.3 ± 0.4	9 ± 2	134 ± 43
Control (n = 22)	0.08 ± 0.03	0.25 ± 0.07	0.98 ± 0.28	0.90 ± 0.06	3.57 ± 0.91	2.9 ± 0.4	6 ± 2	95 ± 44
Superior Mesenteric Artery								
1 (n = 25)	0.18 ± 0.04	0.34 ± 0.07	1.21 ± 0.14	0.85 ± 0.04	3.10 ± 0.52	6.1 ± 10.0	30 ± 11	605 ± 263
1a (n = 11)	0.16 ± 0.03	0.32 ± 0.04	1.23 ± 0.17	0.87 ± 0.02	3.38 ± 0.31	6.0 ± 0.7	28 ± 7	545 ± 157
1b (n = 14)	0.20 ± 0.05	0.37 ± 0.08	1.18 ± 0.09	0.83 ± 0.04	2.75 ± 0.53	6.2 ± 1.2	31 ± 14	684 ± 330
2 (n = 19)	0.16 ± 0.04	0.31 ± 0.10	1.10 ± 0.28	0.85 ± 0.03	3.04 ± 0.45	5.8 ± 0.6	27 ± 6	513 ± 207
Control (n = 22)	0.20 ± 0.05	0.35 ± 0.06	1.37 ± 0.26	0.85 ± 0.03	3.35 ± 0.93	6.1 ± 0.9	29 ± 10	606 ± 89

Abbreviations: EDV, end-diastolic velocity; Vmean, mean velocity; PSV, peak systolic velocity; RI, resistance index; PI, pulsatility index; BFV, blood-flow volume.

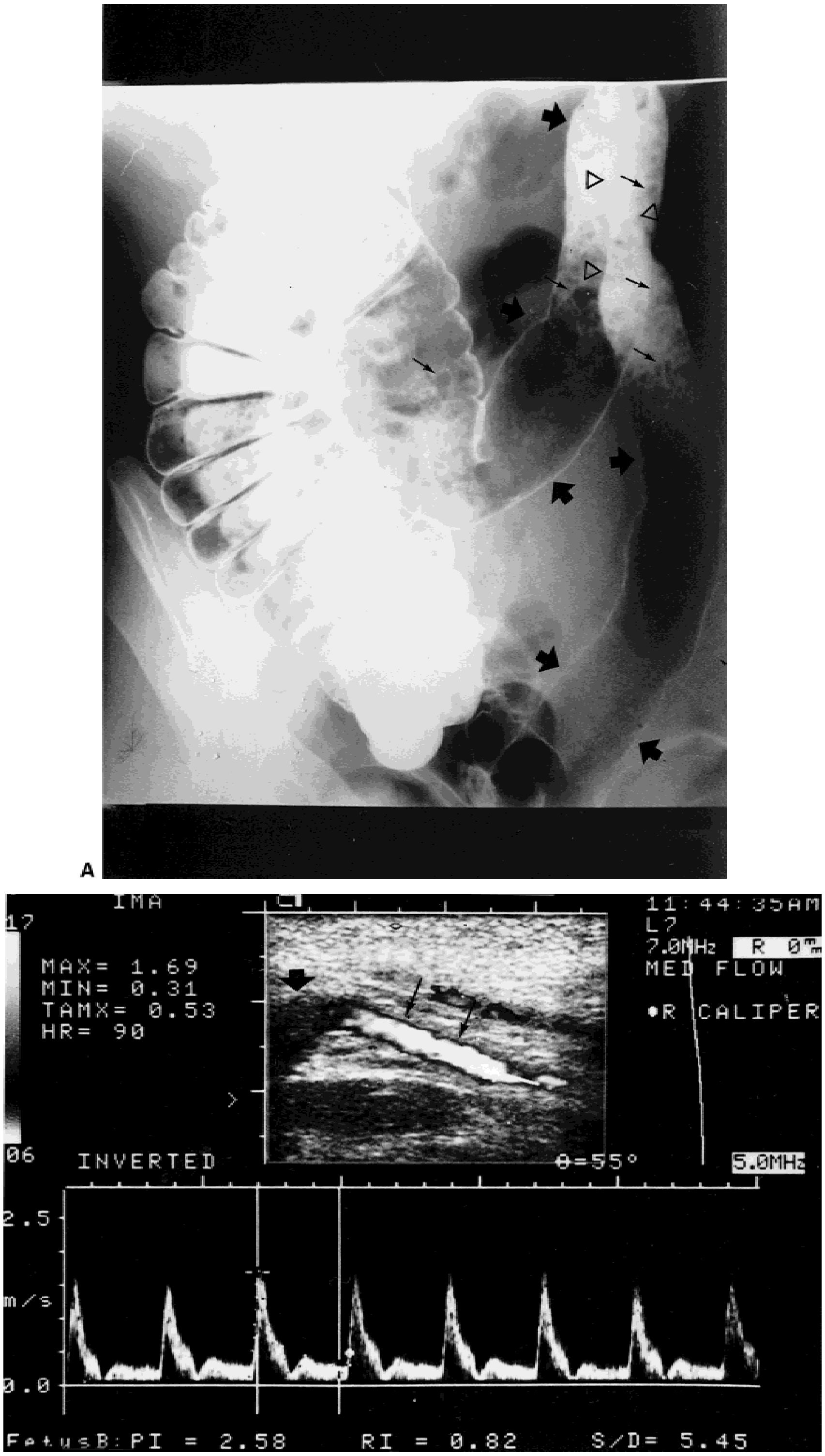
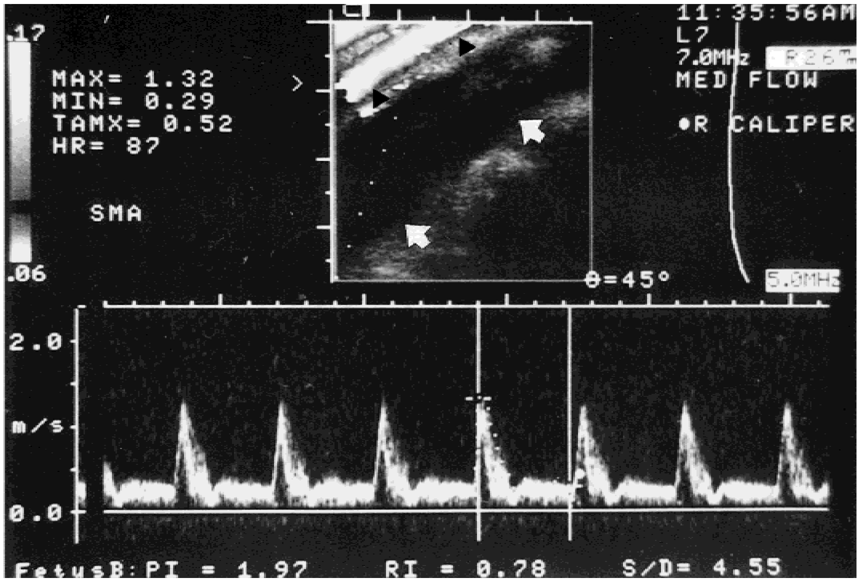


FIGURE 1. Forty-year-old woman with active ulcerative colitis. **(A)** Double-contrast barium enema x-ray study shows narrowing of the proximal descending colon and splenic flexure (arrowheads) and loss of haustral folds in the descending and transverse colon (wide arrows). Extensive acute ulceration with hyperplastic polyp-like mucosa (thin arrows) is visible in the descending and transverse colon. **(B)** Duplex sonogram of the inferior mesenteric artery (IMA) (thin arrows) shows loss of triphasic spectral pattern and increased peak systolic velocity, end-diastolic velocity, and mean velocity. Wide arrow, aorta. **(C)** Duplex sonogram of the superior mesenteric artery (SMA) also shows a loss of triphasic spectral pattern and increased peak systolic velocity, end-diastolic velocity, and mean velocity. Velocities in the IMA are greater than those in the SMA. Arrowheads, SMA; arrows, aorta.



C

FIGURE 1. *Continued.*

group 1b (0.49 ± 0.11 m/second) ($p < 0.05$). The mean PSV of the IMA was significantly higher in group 1a (1.92 ± 0.37 m/second) than in group 1b (1.56 ± 0.50 m/second) ($p < 0.01$). The rest of the mean Doppler blood-flow parameters in the IMA were not significantly different between groups 1a and 1b.

The mean Doppler blood-flow parameters in the SMA were not significantly different between groups 1 and 2 or between either group 1 or group 2 and the control subjects.

The mean EDV in the SMA was significantly higher in group 1b (0.20 ± 0.05 m/second) than in group 1a (0.16 ± 0.03 m/second) ($p < 0.01$). The mean RI and the mean PI in the SMA in group 1b (0.83 ± 0.04 and 2.75 ± 0.53, respectively) were significantly lower than in group 1a (0.87 ± 0.02 and 3.38 ± 0.31, respectively) ($p < 0.01$). The means of the other Doppler blood-flow parameters in the SMA were not significantly different between groups 1b and 1a.

In the IMA in 1 patient with active involvement of the left colon, the PSV, EDV, and Vmean before therapy (1.56 m/second, 0.38 m/second, and 0.60 m/second, respectively) were higher than they were 2 weeks after the beginning of therapy (1.43 m/second, 0.19 m/second, and 0.39 m/second, respectively), and the PI and RI before therapy (1.98 and 0.76, respectively) were lower than they were 2 weeks after the start of therapy (3.15 and 0.87, respectively); however, the SMA flow parameters in this patient remained unchanged. In the IMA and SMA of the 2 patients with involvement of the entire colon, there were significant changes in the flow parameters and spectral patterns 2 weeks after the start of therapy.

DISCUSSION

Sonography can be useful in analyzing the bowel wall and obtaining functional information about most of the affected bowel in Crohn's disease and UC.[9] Color Doppler sonography can show the inflammatory neovascularization of the bowel; this has been useful in assessing whether the disease is in an active phase and differentiating the causes of thickening of the bowel wall.[10,11]

Bowel-wall inflammation causes significant changes in resistance and velocity in the mesenteric blood supply. Angiographic, pathologic, and functional studies have documented both increased blood flow and intense dilatation of arteries in the splanchnic distribution in patients with inflammatory bowel disease (IBD).[12,13] Doppler sonography is a noninvasive method that can evaluate the mesenteric blood flow in patients with IBD. Previous studies have reported SMA Doppler sonographic findings.[2–4] The IMA was also evaluated in healthy subjects and in some patients with occlusions of the distal abdominal aorta and iliac vessel.[14–16] Reports on Doppler sonographic evaluation of the IMA in patients with IBD are rare.[7]

Fasting-state spectral patterns of the SMA and IMA in healthy subjects are triphasic. This triphasic spectral pattern consists of an initial high-velocity forward component during systole and

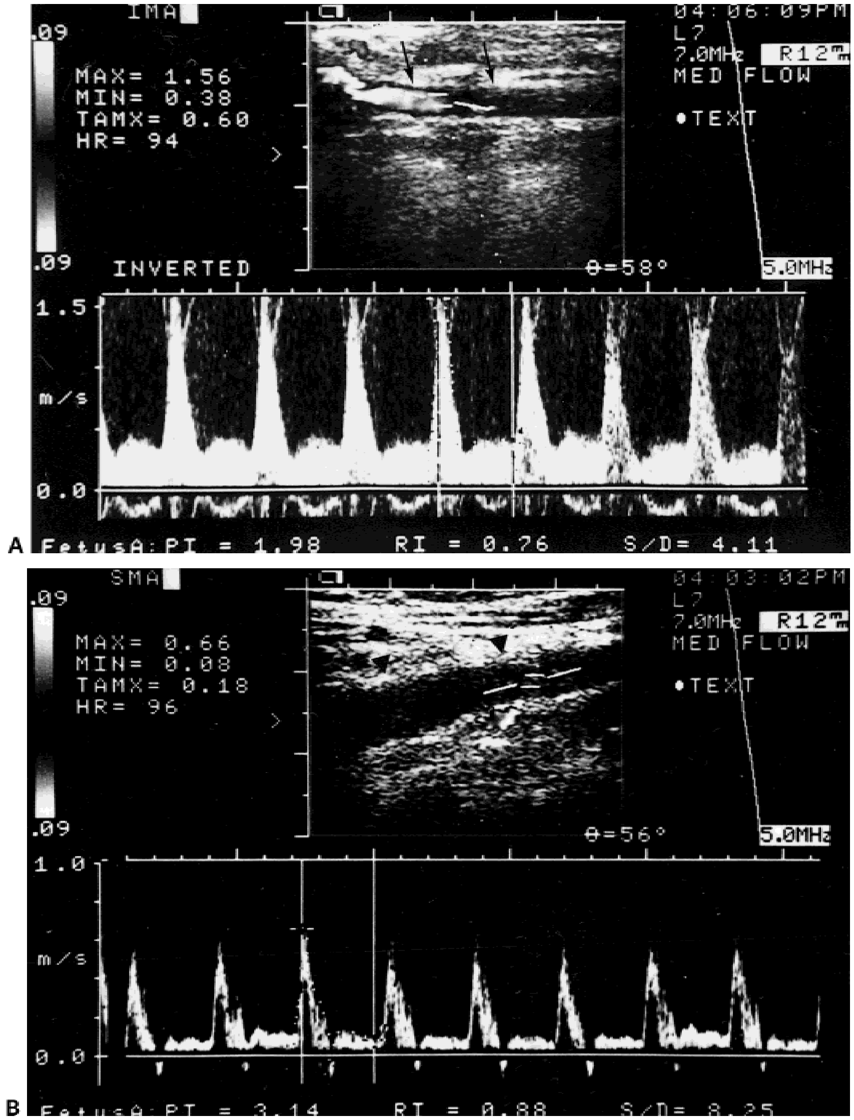


FIGURE 2. Twenty-nine-year-old woman with ulcerative colitis of the left colon. **(A)** Duplex sonogram of the inferior mesenteric artery (IMA) (arrows) in the active phase, before treatment. **(B)** Duplex sonogram of the superior mesenteric artery (SMA) (arrowheads) before treatment. **(C)** Duplex sonogram of the IMA (arrows) in the remission phase, after the start of treatment. **(D)** Duplex sonogram of the SMA (arrowheads) after the start of treatment. Note the significant changes in the spectral pattern and also decreases in the peak systolic velocity, end-diastolic velocity, and mean velocity in the IMA (arrows) in the remission phase of ulcerative colitis after the beginning of therapy in **C.** Note also the absence of change in the SMA (arrowheads) in **B** and **D.** AO and white arrows, aorta.

then a reversed flow of short duration followed by a low-velocity forward flow during diastole. In our study, triphasic spectral patterns were detected in group 2 and in the control group. In group 1, there was loss of early diastolic reversed flow in association with increased forward flow during systole and diastole, indicating increases in PSV and EDV values. These changes were particularly apparent in the IMA in group 1 (Figure 1). The EDV was elevated in the SMA only in the patients with active involvement of the entire colon (group 1b). These results were consistent with the areas perfused by the IMA and SMA. Similarly, Mirk et al[7] reported increased PSV and EDV in the IMA in patients with active UC and Crohn's disease involving the left colon or the entire colon.

From the SMA arise the inferior pancreaticoduodenal artery, middle colic artery, right colic artery, ileocolic artery, jejunal artery, and ileal artery branches. These branches supply the bowel from the distal part of the duodenum up to most of the transverse colon. The IMA is the smallest

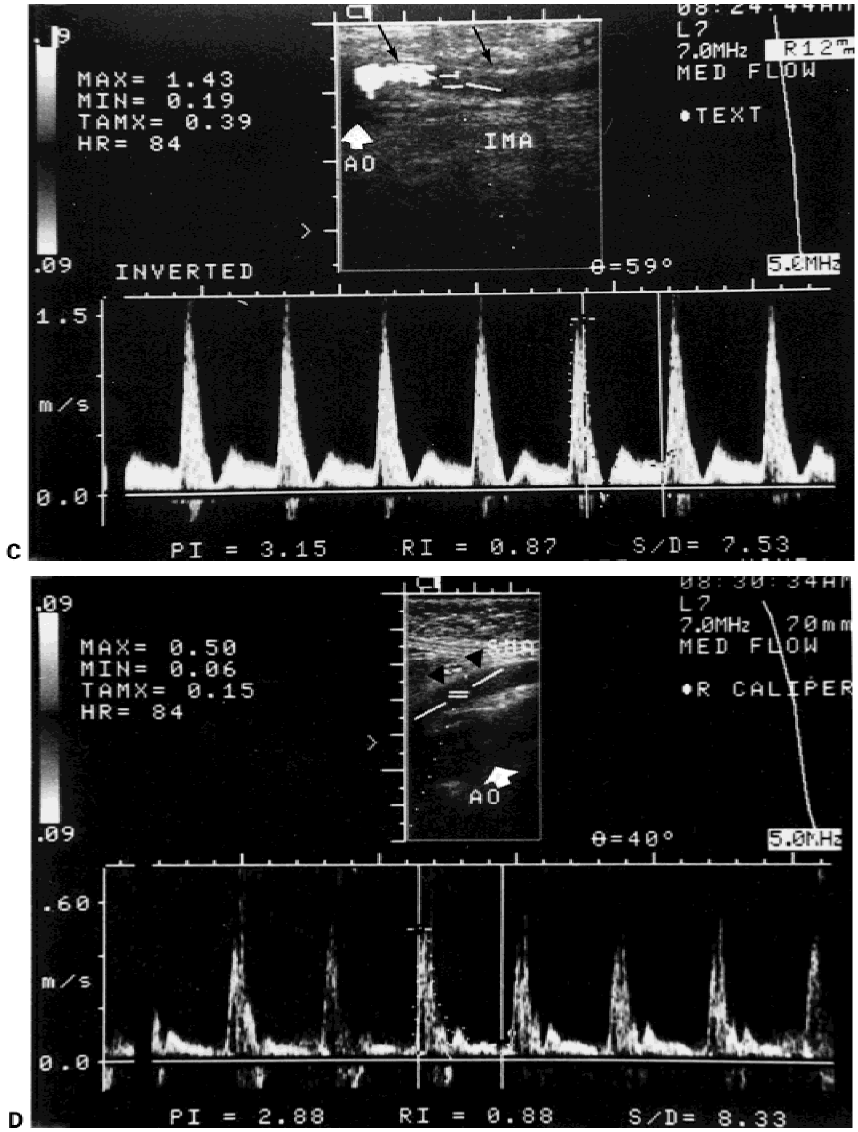


FIGURE 2. *Continued.*

among the mesenteric arteries and gives off the left colic artery, sigmoid arteries, and superior rectal artery. The IMA supplies the distal third of the transverse colon, the splenic flexure, the descending and sigmoid segments of the colon, and the rectum.[17] During large-bowel inflammation, regardless of cause, the vascular bed dilates and congestion develops in the affected area of the bowel, similar to changes seen in any inflammatory process.[18] The massive and persistent vasodilatation, related to the extent of disease, increases blood flow and decreases resistance.

In our study, the increase in the IMA BFV was significant in group 1 owing to increases in the PSV, EDV, Vmean, and diameter of the IMA. Mirk et al[7] have reported significant increases in the BFV of the IMA in patients with active UC and Crohn's disease involving the left or entire colon. In our study, the BFV of the IMA in group 1a approached the BFV of the SMA. However, there was no statistically significant difference in the BFV of the SMA between groups 1 and 2 or between either group 1 or group 2 and the control group. Since UC usually involves the rectum first and then spreads to proximal bowel segments perfused by the IMA, the Doppler values of the IMA are primarily affected before those of the SMA are. Conversely, blood flow in the SMA is likely to be fairly normal when the inflammation is limited to the left colon or rectum because these bowel segments are not supplied by the SMA. In the case of right-colon involvement in UC, the hemodynamic changes may be seen in the branches of the SMA. We expected that these changes would be noticeable in the proximal SMA. In our study, we observed changes in the SMA Doppler parameters in group 1b only.

Although the PI and RI help to evaluate downstream resistance, the PI may reflect the changes better than the RI does, especially in vessels with a triphasic spectral waveform. In some studies,[19–21] the PI has been used to evaluate the downstream impedance of the SMA, although the PI can be influenced by cardiac contractility and vessel characteristics. Although we could not find significant differences in the blood-flow parameters in the SMA between groups 1 and 2 and the control group in our study, there was a significant difference in the SMA Doppler values between groups 1a and 1b. The PI and RI values were lower and the EDV was higher in group 1b, which consisted of patients with pancolitis. Bolondi et al[3] found a statistically significant difference in the mean RI of the SMA between healthy and acutely ill patients with Crohn's disease, but their study did not reveal significant differences in the mean RIs between patients with active and inactive disease. Van Oostayen et al[22] also showed a marked increase in SMA flow volume and a decrease of the RI in patients with active Crohn's disease and concluded that measurement of SMA blood flow may be an important tool for monitoring Crohn's disease objectively.

In our study, the mean BFVs in the SMA in all patient groups and in the control subjects were not significantly different. Although the mean BFV in the SMA in group 1b (684 ± 330 ml/minute) was higher than in group 1a (545 ± 157 ml/minute), the difference was not statistically significant. This could be due to anatomic variations in the area supplied by the IMA and SMA. The midportion of the transverse colon is supplied by the middle colic branch of the SMA in the majority of cases, while it is supplied by the IMA in only 3% of cases.[23] The lack of statistical significance could also be due to the marginal artery, which forms a single arterial trunk around the concave margin of the colon. The marginal artery begins at the ileocecal junction and ends where it anastomoses less freely with the superior rectal artery.[17] Another reason could be the asymptomatic involvement of intestinal segments other than the colon that could be supplied by the SMA.

In the present study, the PI of the IMA was significantly lower in group 1 than in group 2 and significantly lower in group 1 than in the control group. The RI of the IMA was not significantly different between these groups. Mirk et al[7] reported a decreased PI in patients with active UC and Crohn's disease involving the left or entire colon. In our study, the RI and PI of the IMA between groups 1a and 1b were not significantly different.

Many physiologic conditions may influence the Doppler sonographic flow parameters in the mesenteric vessels, especially in the SMA. Eating can significantly increase the blood-flow parameters (Vmean, BFV, PSV, and EDV), but exercise reduces mesenteric blood flow in healthy subjects.[24,25] To eliminate these physiologic variations, we examined the patients in a fasting state under resting conditions.

Doppler sonography is a technically demanding and never totally reproducible examination because of interobserver variability and numerous patient-related factors.[21,26–35] Breath-holding is important, especially to obtain an adequate spectral pattern in the mesenteric vessels with small diameters. Any error in determining the angle of insonation and in the measurement of vessel diameter may affect velocity and flow-volume calculations.

It is important to observe the abdominal aorta and iliac vessels by sonography to rule out any occlusive or stenotic condition before evaluating the mesenteric vessels. Erden et al[16] reported that aortic and iliac occlusion or severe stenosis significantly changes the Doppler waveform pattern and flow parameters of the IMA.

Quantitative measurements of the SMA and IMA blood flow may contribute not only to the diagnosis of UC but also to the evaluation of the efficacy of therapy. We evaluated 6 patients in group 1 during their treatment. In 1 patient with active involvement of the left colon, the results of the IMA Doppler evaluation before therapy and 2 weeks after the beginning of therapy during the remission phase were significantly different. SMA flow parameters were not significantly changed (Figure 2). We also noted significant changes in flow parameters and spectral patterns in the SMA in 2 patients with entire-colon involvement before and 2 weeks after the start of therapy.

In conclusion, active UC is strongly associated with increases in the BFV and flow volume, especially in the IMA. In the SMA, only the EDV, PI, and RI were altered in patients with active involvement of the entire colon. We can evaluate the extent of large-bowel inflammatory disease and the efficacy of therapy by evaluating the IMA and SMA flow parameters simultaneously. Abnormal Doppler findings in the IMA and SMA are related to the extent of the involvement of the colon and may be useful in evaluating the response to treatment.

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