Inferior mesenteric venous sampling to detect colonic ischemia: A comparison with laser Doppler flowmetry and photoplethysmography

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Purpose: No single method has been identified that accurately and reliably detects patients with impending bowel infarction during aortic reconstruction. Serial sampling of blood gas from the inferior mesenteric vein (IMV) for detecting colonic ischemia was compared with two previously described techniques: laser Doppler flowmetry (LDF) and photoplethysmography.

Methods: Nine dogs underwent induced partial colonic ischemia followed by complete ischemia. Serial IMV blood gas measurements were obtained at four intervals: baseline, partial ischemia, complete ischemia, and reperfusion. Simultaneous direct colon wall LDF and PPG measurements also were obtained.

Results: Changes in pH, Po_2, O_2 saturation, and Pco_2 demonstrated progressive acidosis, hypoxemia, and hypercapnia in association with progressive arterial occlusion and a reversal of these trends toward baseline after restoration of flow. The absence of a pulsatile photoplethysmography tracing and oxygen saturation less than 90% were predictive of altered perfusion but could not differentiate partial from complete ischemia. Although the differences in mean LDF values were statistically different during ischemia and reperfusion, there was considerable variability between each measurement.

Conclusions: Analysis of blood gas from the IMV and pulse oximetry are useful techniques for detecting colonic ischemia, but only the former can distinguish partial from complete ischemia. The variability in colonic measurements with LDF limits its usefulness for detecting levels of colonic perfusion. (J VASC SURG 1995;22:271-9.)

Interruption of direct or collateral circulation to the left colon during aortic reconstructive procedures can cause ischemic colitis. The reported incidence of this condition is 2% to 10%, and the associated mortality rate ranges from 40% to 100%.[1-4] Routine sigmoidoscopy after ruptured abdominal aortic aneurysm reveals various degrees of intestinal ischemia in 60% of patients.[5] Data from the National Center for Health Statistics show that 65,000 aortic reconstructive procedures were performed in 1985; among these there were 1300 cases of colonic ischemia, causing an estimated 700 deaths.[6] Three degrees of colonic ischemia have been described: transient mucosal ischemia, muscularis ischemia with subsequent stricture formation, and transmural gangrenous ischemic colitis. Death is in large part due to the delay in diagnosis until irreversible changes have occurred. Detection of colonic hypoperfusion before closure of the abdomen would be clinically valuable for identifying patients at increased risk for the development of ischemic colitis.

The intraoperative assessment of intestinal viability remains a challenging problem frequently faced by surgeons.[7-11] Although the subject of multiple clinical

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studies, there is no proven, well-accepted method of quantifying critical levels of perfusion that predicts irreversible intestinal ischemia.[1,5,8,11,12] Many cases of intestinal ischemia could be avoided by additional revascularization procedures, such as inferior mesenteric artery (IMA) reimplantation or bypass to an internal iliac artery (IIA), if hypoperfusion could be identified during operation.

This study was designed to evaluate the efficacy of serial inferior mesenteric venous (IMV) sampling of blood pH, Po_2, Pco_2, HCO_3^-, and O_2 saturation for assessing colonic perfusion in a dog model. This previously undescribed technique was compared with two described methods of assessing intestinal perfusion: laser Doppler flowmetry (LDF) and photoplethysmography (PPG).

MATERIAL AND METHODS

Experimental designs. Fifteen adult mongrel dogs of either sex (18.7 to 25 kg) were used in compliance with the "Principles of Laboratory Animal Care" and the *Guide for the Care and Use of Laboratory Animals* (NIH Publication No. 86-23). Dogs were chosen because their large intestine and colonic arterial blood supply closely resemble those of human beings. Anesthesia was induced with methohexital (Brevital, 20 mg/kg intravenously) and was maintained with 1% to 3% halothane after intubation with a cuffed 8.0 mm endotracheal tube. The dogs underwent ventilation on a volume-cycled ventilator at a tidal volume of approximately 340 ml with 40% inspired oxygen and a respiratory rate of 20 breaths per minute. Heat lamps and heating blankets were used to maintain esophageal temperatures at 37° C. Catheters were placed in the femoral arteries and jugular veins for monitoring of blood pressure, heart rate, and central venous pressure. Three to four liters of fluid (Plasmalyte A injection; Baxter Health Care Corp., Deerfield, Ill.) was administered throughout the procedure to maintain preoperative blood pressure, heart rate, and central venous pressure. All animals received heparin (5000 units) intravenously at the beginning of the procedure.

In each animal, a midline laparotomy was performed under sterile conditions, and the colonic mesenteric vessels were dissected. A 3-0 silk suture was placed on the antimesenteric border of the left colon where it is supplied by the IMA as a landmark to ensure that the various intraoperative measurements and biopsy specimens (described below) were obtained from the same area of colon. The IMV was cannulated with a 20-gauge catheter several centimeters distal to the junction of the IMV and splenic vein and directed away from the central circulation. The catheter was flushed with heparinized saline solution after each sample was obtained, and it remained in place for analysis of subsequent samples. Blood gas analysis was performed within 5 minutes after each sample was obtained (Instrumentation Laboratories 1400 BGE; Instrumentation Laboratory, Lexington, Mass.). At the end of each operation, the catheter was removed, and the IMV was ligated.

A clinically available laser Doppler scanner (Vasamedics Laserflo Blood Perfusion Monitor; Vasamedics Inc., St. Paul, Minn.) with an attached flow probe (model JSP 4402; Vasamedics, Inc.) was used.[7,10,13-15] The probe was applied to the left colon (Fig. 1) approximately 3 cm proximal and distal to the 3-0 silk landmark ligature. Cyclical flow values were observed and followed over a 60- to 90-second interval until a peak value was obtained, and the probe was removed.

A commercially available pulse oximeter with a gas-sterilized probe (Ohmeda Biox 3740 Pulse Oximeter; EARPROT 1 8122-003; Ohmeda, Louisville, Colo.) also was applied directly to the left colonic serosa to the same locations as the laser Doppler flow probe (Fig. 1). The pulse oximeter displayed continuous transcolonic oxygen saturation and a photoplethysmographic tracing that could easily be distinguished as pulsatile or nonpulsatile (on the basis of both the waveform and the correlation with the heart rate from an electrocardiographic tracing). The most consistent transcolonic oxygen saturation level observed after 30 to 60 seconds and the presence or absence of a pulsatile tracing were recorded. For a comparison of local with regional perfusion, PPG measurements also were obtained from the proximal right colon because this area of intestine was not affected by alterations in left colonic perfusion.

Torbugesic (butorphanol tartrate, 0.1 mg/kg intramuscularly) was given every 6 hours for postoperative analgesia. Euthanasia was performed with an overdose of intravenously administered 25% sodium pentobarbital (Sleepaway, approximately 100 mg/kg), consistent with the recommendations of the Panel on Euthanasia of the American Veterinary Medical Association.

Histologic study. Full-thickness biopsy specimens from the left colonic wall were obtained to correlate alterations in perfusion with histologic evidence of ischemia. Biopsy specimens, 1 × 1 cm, were taken from sites immediately adjacent to the 3-0 silk landmark suture. Tissue samples were fixed in formalin for analysis of paraffin-embedded,

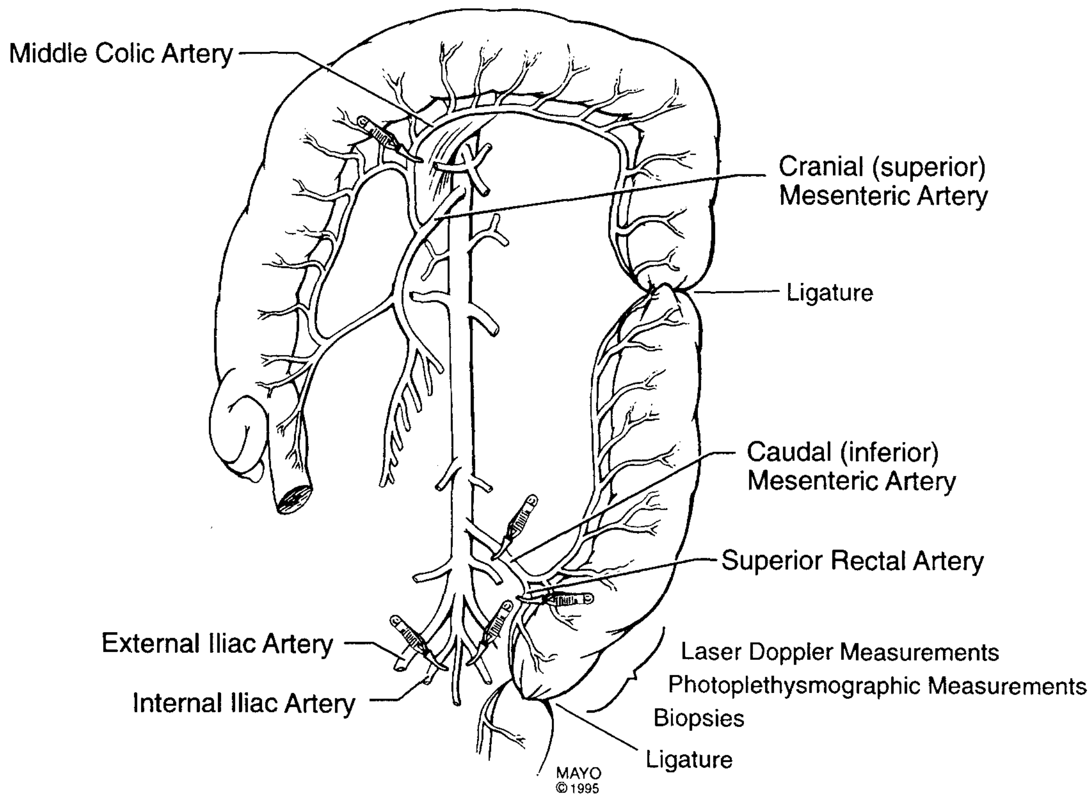

Fig. 1. Study design to induce ischemia; arterial anatomy of dog. (Mayo Foundation. Used with permission.)

hematoxylin-eosin-stained sections. Each section was evaluated for the presence or absence of ischemia by a pathologist blinded to the clinical circumstances from which the tissue was obtained. A grading scale was developed on the basis of previous histologic studies describing intestinal pathologic findings,[13,16-19] as follows: grade 0, normal; grade 1, mucosal edema with vascular dilation; grade 2, superficial muscularis propria necrosis with neutrophil infiltration, with or without mucosal hemorrhage; grade 3, necrosis of overlying surface epithelium, with or without neutrophil infiltrate; grade 4, sloughing of less than half the mucosa; grade 5, sloughing of more than half the mucosa; grade 6, submucosal necrosis; and grade 7, transmural necrosis. Necrosis of the muscularis propria (grade 7) was taken to represent irreversible ischemia.

Protocols

Study 1. The initial protocol involved five animals and was designed to develop two distinct levels of colonic ischemia: (1) partial, or mucosal changes (grades 2 to 4), and (2) complete, or transmural necrosis (grade 7). In the first two animals, the IMA, middle colic artery (MCA), and superior rectal artery (SRA) were ligated with a 0 silk ligature. Additional collateral and transmural perfusion was interrupted by ligating the colon itself in the third and fourth dogs. Umbilical tape was applied to the proximal and distal aspects of the left colon. In one of these animals, the IIAs also were ligated to ensure more complete and proximal interruption of colonic perfusion. The fifth dog underwent operation as the control. The IMA, MCA, SRA, and IIAs were dissected but not ligated, and biopsy specimens were obtained to determine whether any histologic changes in the left colon could be detected from the effects of operation, anesthesia, and an open abdomen. In each animal, biopsy specimens were obtained from the left colon at 1, 2, and 3 hours after ischemia and at reexploration at 24 or 48 hours to determine the degree of colonic ischemia and the time required for the histologic changes to develop. Biopsy specimens also were obtained from the right colon at reexploration to determine whether there was any histologic evidence of global colonic hypoperfusion.

Study 2. Ten animals were used for the second protocol. However, data from one animal were excluded because of technical difficulties in obtaining blood samples. Each animal served as its own control and underwent sequential alterations in perfusion that were based on study 1. Because occlusion of the IMA, MCA, and SRA in study 1 caused incomplete but significant ischemia (grade 4 or 5), ligation of the IMA alone was chosen as the model of partial ischemia for study 2. Interruption of the IMA, MCA, SRA, IIAs, and colon caused transmural infarction in study 1 and was chosen as the model of complete ischemia for study 2. Sequential alterations in perfusion were performed in each animal (baseline to partial ischemia to complete ischemia to reversal of all occlusion). Eleven sequential measurements were obtained during the four distinct levels of perfusion (Table I): baseline; 15 and 30 minutes after partial ischemia; 15, 30, 45, and 60 minutes after complete ischemia; and 15, 30, 45, and 60 minutes after reperfusion. The baseline measurement was obtained after dissection of the mesenteric vessels and placement of the IMV catheter. Doppler ultrasonography with a sterile Doppler probe confirmed the loss of pulsatile flow along the mesenteric surface of the distal left colon. Reperfusion was accomplished by removing all vascular clamps and the colonic umbilical tapes. Doppler ultrasonography confirmed the return of arterial flow in the previously clamped vessels. The animals were allowed to recover, and after 48 hours reexploration was performed to obtain colonic biopsy specimens for determination of the degree of colonic ischemia.

Statistics

Repeated measures analysis of variance was used to compare mean values among the four time points. Differences between the perfusion groups were analyzed post hoc with paired *t* tests. Values were considered to be statistically different when the *p* value was less than 0.05. To compare the variability of each test with that of the others, a reliability coefficient[20] was calculated for each test for the repeated measurements obtained during a representative interval (15, 30, 45, and 60 minutes after complete ischemia). The reliability coefficient is a measure of the variance between dogs divided by the total variance (the variance between dogs and the variation in repeated measures in the same dog).

RESULTS

Study 1. In the control animal, the sequential biopsy specimens revealed normal colonic mucosa with a normal muscularis propria. In the two dogs with ligation of the IMA, MCA, and SRA, no histologic evidence of colonic ischemia was observed from three sequential 1-hour intraoperative specimens. At reexploration after 24 to 48 hours, there was partial to complete mucosal necrosis with submucosal edema and mild neutrophilic infiltration, but the muscularis propria was intact (grades 4 and 5). In the two dogs with the additional ligation of the colon or the IIAs and colon, superficial mucosal sloughing with edema of the upper lamina propria and vascular ectasia (grade 1) was evident after 120 minutes. Transmural infarction with necrosis (grade 7) was evident in both animals at reexploration after 48 hours. Biopsy specimens obtained from the right colon in these animals to detect global alterations in perfusion revealed no histologic evidence of ischemia.

Study 2. Histologic assessment. In all nine experimental animals, biopsy specimens obtained after 48 hours revealed changes that ranged from normal to superficial mucosal sloughing (grades 0 to 2). The submucosa and circular muscularis propria layers were normal in all cases. At 48 hours, there was no histologic evidence of infarction in any animal.

LDF. Mean LDF values significantly decreased (Table II) from baseline to partial ischemia to complete ischemia and subsequently increased after reperfusion. However, during the actual measurements, there were wide fluctuations in individual values that often did not correlate with the level of perfusion. Only when the mean of four values was determined did the value correlate with the level of perfusion. The low reliability coefficient (Table III) demonstrates the high variation for repeated LDF measurements on each individual dog with this technique.

PPG. Both the presence of a pulsatile tracing and a transcolonic oxygen saturation of more than 90% were predictive of adequate intestinal perfusion. All transcolonic oxygen saturation values obtained during "normal" perfusion (measurements from the left colon during baseline or reperfusion and from the right colon during all intervals) were more than 90%, and 52 of 54 were pulsatile. Mean transcolonic oxygen saturation values revealed significant desaturation during progressive hypoperfusion and a recovery toward baseline after reperfusion. Among the PPG tracings, 33% were pulsatile during partial ischemia, and 3% were pulsatile during complete ischemia. These differences were not statistically significant ($p = 0.056$); however, this finding may reflect the small sample size. Because the photoplethysmographic machine requires a pulsatile signal to accurately calculate an oxygen saturation, when the

Table I. Study 2 design

Intervention time (min.)	Level of perfusion*			
	Baseline	*Partial ligation*	*Complete ligation*	*Reperfusion*
Baseline				
0	X			
IMA interrupted				
15		X		
30		X		
IMA, MCA, SRA, IIAs, colon interrupted				
45			X	
60			X	
75			X	
90			X	
Release of all clamps				
105				X
120				X
135				X
150				X

*Sampling of central venous blood gases and IMV bloocd gases, right colonic PPG, left colonic PPG, and LDF.

Table II. Bowel ischemia as measured by LDF and PPG in nine dogs

	*Baseline**	*Partial ischemia**	*Complete ischemia**	*Reperfusion**
Laser Doppler flow, ml/min/100 gm	32.0 ± 11.1	13.0 ± 5.8†‡	7.1 ± 2.8†	19.3 ± 12.4‡
Photoplethysmography, % saturation	96.8 ± 1.2	88.3 ± 5.3†‡	76.8 ± 6.1†	96.5 ± 1.7 ‡

*Values are mean ± SD; $p < 0.05$ (repeated measures analysis of variance).
†Statistically significant difference compared with baseline.
‡Statistically significant difference compared with complete ischemia.

signal was nonpulsatile or a transcolonic oxygen saturation of less than 90% was obtained, neither the presence or the absence of hypoperfusion nor the degree of hypoperfusion could be precisely determined. Our data reflected this unreliability. Large cyclical fluctuations in transcolonic oxygen saturation were observed during each measurement and during repeated measurements at the same interval (partial ischemia range, 74.5% to 95.5%; complete ischemia range, 65.5% to 89.3%). This resulted in the low reliability coefficient demonstrated in Table III.

IMV sampling. IMV Po_2, Pco_2, pH, and O_2 saturation values were all predictive of the level of perfusion. Mean pH, Po_2, and O_2 saturation values decreased significantly (Table IV) with progression of arterial occlusion (baseline to partial to complete ischemia) and increased toward baseline after reperfusion. Mean Pco_2 values increased significantly with progressive levels of hypoperfusion and decreased toward baseline with reperfusion. Mean HCO_3^- values ranged from 21.1 to 23.0 mEq/L and were not statistically different between any two intervals. Sampling of pH, Po_2, Pco_2, and O_2 saturation differentiated partial from complete ischemia when individual measurements were considered separately or when the mean value of repeated measurements during the same interval was considered. The high reliability coefficients (Table III) for pH, Po_2, Pco_2, and O_2 saturation demonstrate the relatively low variation for repeated measurements on the same dog.

Blood samples obtained from the jugular vein did not reveal evidence of systemic hypoperfusion. The changes in pH (range, 7.44 to 7.48), HCO_3^- (range 23.0 to 23.7 mEq/L), Po_2 (range 64.1 to 66.7 mm Hg), and O_2 saturation (range 93.1% to 93.9%) values during progressive hypoperfusion and reperfusion did not reach statistical significance between any two intervals. Pco_2 values significantly increased during progressive ischemia (range 30.6 to 34.0 mm Hg), but much less than the changes from the IMV Pco_2 samples (range 31.4 to 52.7 mm Hg).

Table III. Comparison of reliability of each intraoperative test

Intraoperative test	*Reliability coefficient*[20]
IMV Pco_2	0.845
IMV pH	0.79
IMV O_2 saturation	0.752
IMV PO_2	0.613
IMV HCO_3-	0.505
Pulse oximetry	0.507
LDF	0.414

DISCUSSION

Each of the intraoperative tests was performed during four distinct periods (baseline, partial ischemia, complete ischemia, and reperfusion) because of their relevance to clinical situations. Ligation of the IMA alone was chosen as our model of partial ischemia because it most closely resembles the clinical situation of IMA interruption during aortic reconstruction. A reproducible model of transmural left colonic infarction was developed in study 1 by complete ligation of all direct and collateral colonic perfusion. This simulates the situation of inadequate perfusion at the conclusion of aortic reconstructive procedures. The various intraoperative tests were compared to determine values predictive of this lethal complication. Measurements were repeated after reversal of complete vascular occlusion in study 2 animals to determine whether reconstitution of flow could reverse the infarction that developed in study 1 animals with complete ligation of colonic perfusion and to determine whether these techniques could predict the adequacy of reperfusion.

Although multiple methods of detecting intestinal ischemia during operation have been described, most authors agree that there is no well-accepted, proven method to determine which patients require additional reconstructive procedures. We hypothesized that serial sampling of blood gases from the IMV would be a simple, safe, accurate, and direct method of detecting colonic ischemia. Because the IMV is the most anatomically direct venous drainage of the distal left colon in human beings and dogs, measurements from this vessel should accurately reflect the adequacy of perfusion in this portion of intestine. We found that Po_2, Pco_2, pH, and O_2 saturation values from the IMV were accurate and reliable indicators of the degree of ischemia and the adequacy of reperfusion. This finding was true regardless of whether individual measurements within a given interval were considered separately or whether the mean of repeated measurements was considered.

Progressive acidosis, hypercapnia, hypoxemia, and desaturation developed with incremental reductions in perfusion, and there was a reversal of these trends toward baseline after reperfusion. Significant differences could be detected between partial and complete ischemia (Table IV). From baseline to partial ischemia, pH decreased by a mean of 0.08, but from baseline to complete ischemia, the mean reduction was 0.26. Po_2 values decreased to 71.5% of baseline during partial ischemia and 56.7% of baseline during complete ischemia. Similarly, O_2 saturation decreased from 82.8% of baseline to 57% from partial to complete ischemia. Elevations in Pco_2 were also significant and differentiated partial ischemia (118.6% of baseline) from complete ischemia (170.4% of baseline).

We compared this technique with two previously described methods of detecting intestinal ischemia that have shown promise but warrant further investigation: LDF and PPG. LDF values seemed to correlate with the level of perfusion when the mean value of repeated measurements during the same interval was determined. However, averaging the values had the effect of blunting the wide variation observed during each measurement. Other investigators have also found significant variation in repeated LDF measurements. Variation may result from recording artifacts as a result of peristalsis, variable probe and equipment design, or loss of optical coupling between the probe and the tissue surface.[10] Krohg-Sørensen et al.[7] found that four repeated recordings had to be averaged to obtain reproducible LDF values with an estimated precision of 10% in normal colon. Ahn et al.[10] found that colonic LDF values in 62 patients varied between 5 and 42 ml/min per 100 gm.

This study supports the findings of other investigators[1,6,11,21,22] that pulse oximetry can be applied to the intestine and can measure transcolonic oxygen saturation and arterial pulsatility. The presence of a pulsatile tracing and a transcolonic oxygenation of more than 90% were predictive of perfusion (or reperfusion) that was adequate for colonic viability. However, the usefulness of this technique is limited by its inability to differentiate partial from complete hypoperfusion or from adequate perfusion when the pulsatility of the signal is lost.

A model of reversible colonic ischemia and infarction that mimics the clinical situation that occurs in patients who undergo aortic reconstruction was successfully developed in the dog. IMV blood gas

Table IV. The pH, Po_2, O_2 saturation, Pco_2, and HCO_3- from IMV blood during alterations in colonic perfusion in nine dogs

	*Baseline**	*Partial ischemia**	*Complete ischemia**	*Reperfusion**
pH	7.47 ± 0.04	7.39 ± 0.07†‡	7.21 ± 0.15†	7.40 ± 0.07†‡
Po_2, mm Hg	59.9 ± 14.7	40.7 ± 7.6†‡	32.2 ± 4.5†	52.0 ± 12.2‡
O_2 saturation, %	91.3 ± 5.3	75.3 ± 13.1†‡	52.4 ± 13.4†	86.4 ± 6.6‡
Pco_2, mm Hg	31.4 ± 5.4	36.9 ± 6.2†‡	52.7 ± 14.9†	36.9 ± 6.7†‡
HCO_3-, mEq/L	23.0 ± 3.3	22.6 ± 2.6	21.1 ± 2.6	22.9 ± 2.2

*Values are mean ± SD; $p < 0.05$ (repeated measures analysis of variance).
†Statistically significant difference compared with baseline.
‡Statistically significant difference compared with complete ischemia.

sampling, LDF, and PPG were compared to determine their ability to detect colonic hypoperfusion in this model. Blood gas analysis from the IMV is a previously undescribed but safe and accurate method to detect and differentiate partial from complete colonic ischemia. The application of a standard pulse oximeter to the colon can simply and reliably detect adequate colonic perfusion when the transcolonic oxygen saturation is more than 90% and the PPG tracing is pulsatile. However, the loss of a pulsatile tracing and subsequent unreliable transcolonic oxygen saturation levels make differentiating partial from complete ischemia unreliable. Detecting bowel ischemia by IMV blood gas analysis may reduce the morbidity and death resulting from ischemic colitis after aortic reconstructive procedures.

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DISCUSSION

Dr. Calvin B. Ernst (Detroit, Mich.). It is important to prevent ischemic colitis after aortic reconstruction because once it occurs, particularly the transmural variety, the mortality rate approaches 90%. Although the frequency varies depending on whether routine postoperative flexible sigmoidoscopy is used, clinically manifest ischemic colitis occurs in about 2% of patients after aortic reconstruction, most commonly for aneurysmal disease. Any study to better identify patients at risk for development of this potentially lethal complication will therefore have a favorable impact on results. To date all studies including IMA stump blood pressure measurements, Doppler detection of sigmoid blood flow, PPG, and transcolonic oxygen saturation measurements provide only data during the operation and do not provide for postoperative monitoring.

The study by Avino et al. is no different than those previously described in that data were only obtained during operation. Although the authors have documented that LDF and PPG measurements vary widely and may not be reliable and IMV blood gas and pH measurements are more reliable, I wonder about the clinical practicality of such measurements. For example, cannulating the IMV in the clinical situation with the highest incidence of colon ischemia, namely a ruptured aneurysm, with a large left flank hematoma may be virtually impossible.

Now their animal model with total deprivation of colonic blood flow is not analogous to the clinical situation, although the IMA occlusive analogy may be. The IMA, MCA, and the SRA were occluded in their phase I study to simulate partial colonic ischemia, yet in the second phase of the study, only the IMA was occluded to simulate partial ischemia. The authors should explain this discrepancy between the two phases of the study. Also, biopsies were only obtained during phase I of the study. So occluding only the IMA may not cause as much partial ischemia as one would believe.

Although this study may help predict when colonic ischemia may develop only on the basis of operative measurements, a more helpful technique would be one applicable in the operating room and also after operation as a continuing monitor of adequate colonic perfusion because some patients may be vulnerable to ischemic colitis and mesenteric perfusion in the recovery room and the intensive care unit.

To this end we have performed a pilot study that involves 39 patients using an intraluminal sigmoid pH tonometer to continuously monitor sigmoid mucosal pH during and after operation. It appears from our data and those in the literature that a pH below 7.0 signals colonic hypoperfusion and mucosal ischemia that can then be confirmed by flexible sigmoidoscopy.

I commend the authors for trying to refine our ability to predict development of ischemic colitis after aortic reconstruction, but to be meaningful this type of study must be performed in patients undergoing aneurysm repair, and I encourage use of postoperative routine colonoscopic examination to document whether the experimental study has clinical application.

Dr. Anthony J. Avino. To answer a few of your questions, as far as the safety of ligating the IMV, in our clinical study we have so far analyzed 18 patients and we have been able to oversew the site where the catheter was inserted in 17 of the 18 patients and only had to ligate the vein in one patient. We initially believed that this was a safe technique because the IMV is not infrequently ligated for exposure during aortic reconstruction without untoward events. Also, in the animal model in which we ligated the IMV in every case, there was no significant histologic evidence of ischemia after arterial reperfusion in any animal.

In the study 2 animals all dogs at 48 hours underwent biopsies, and in the 10 animals that underwent reperfusion there was no evidence of ischemia.

As far as the clinical application of this, each measurement was performed over a 6-second interval. In the patient model, the length of time to obtain these measurements actually only added a few minutes to the case. Once the catheter was placed in the IMV, it was simply a matter of aspirating 1 ml of blood to obtain the measurement. So this is a very quick test. The O_2 saturation just involves clipping the pulse oximeter probe to the colon or placing the laser Doppler probe on the serosal surface of the colon.

To answer your question regarding the discrepancy between study 1 and study 2 for our model of partial ligation, in SRA. That was in an attempt to develop our model of complete ischemia, but only partial ischemia occurred so we ligated additional blood flow to establish complete ischemia. For the study 2 animals, we ligated only the IMA because we knew anatomically that this was the main blood supply to the colon, and we wanted this model of partial ischemia to be clinically relevant.

We agree that postoperative monitoring is beneficial and that this study is purely for intraoperative monitoring but that was our initial goal, to identify patients at most risk during operation before irreversible changes occur because the mortality rate is so high if not detected early.

Dr. Timonthy R. S. Harward (Gainesville, Fla.). We have tried very hard to use the dog as a model for both acute and chronic ischemia. Unfortunately we have had a lot of problems with this model because of unnamed mesenteric collateral vessels. Much as you have done before, we have gone through all the dog anatomy books and were very enamored by its very striking similarity to the human anatomy. We have done things like tying off all three mesenteric arteries, and the dogs continued to gain weight, thus making me a bit worried about the usefulness of the dog as a model to study mesenteric ischemia.

I also support Dr. Ernst's comments about the use of the Fiddian-Green tonometry catheter. We have found it in our laboratory to be an excellent monitor of colonic and small bowel ischemia. It is one of those techniques that seems to have been forgotten in the clinical world after it was developed at the University of Michigan. It is something that you can use not only during operation but also in the postoperative period. Most surgeons who deal with colonic ischemia are very worried about the patient on day 2, 3, or 4 when the heart is not working well and there is poor collateral circulation to the colon, the tonometer catheter works quite nicely in predicting upcoming ischemic events.

Did you vary the oxygen content that the animal inhaled? In the operating room, we have noticed that as the anesthesiologist increases the oxygen inhalation up to 100%, the venous Po_2 values change tremendously.

The easiest way to deal with this problem is to reimplant all IMAs. Once we started doing that, we have not had a single episode of colonic ischemia related to a patent IMA. Most of our problems occur in people who already have occluded IMAs.

Dr. Avino. To answer your first question regarding the O_2 content delivered, all dogs were inspired on a ventilator at 40% inspired oxygen at 20 breaths/min and the central venous pressure and venous blood gases were monitored every 15 minutes. We aggressively maintained heart rate, blood pressure, and central venous catheter at preoperative levels and did not experience wide variation in central venous saturations.

With regard to the problem with developing complete ischemia, we were similarly impressed by the dogs' collateral circulation and how difficult it was to develop complete ischemia.