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Monitoring Hepatic Venous Hemoglobin Oxygen Saturation in Patients Undergoing Liver Surgery

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Hepatic venous oxygen saturation (Shv_{O_2}) was continuously monitored in 33 consecutive patients undergoing hepatic lobectomy. Fiberoptic pulmonary artery catheters were inserted into the hepatic vein (HV) and in the pulmonary artery through the right internal jugular vein before anesthetic induction. The success rate and mean time for HV catheterization were 100% and 14 min, respectively. The only complication of the procedure was nonsustained atrial or ventricular arrhythmias. Eighteen patients showed decreases in Shv_{O_2} to less than 30% at skin incision, at temporary cessation of hepatic inflow, and/or at surgical manipulation of the liver. Clinical HV catheterization was easy to accomplish and may be a valuable technique in studying the extent and significance of hepatic ischemia during liver surgery. (Key words: Equipment: oximeter pulmonary artery catheter. Liver: oxygenation. Monitoring: hepatic venous oxygen saturation; mixed venous oxygen saturation. Surgery: hepatic.)

HEPATIC BLOOD FLOW (HBF) may be altered by surgical manipulations and anesthetics.[1] Although there are several techniques to determine HBF,[2] their clinical usefulness is limited. Measurements of hepatic venous oxygen saturation (Shv_{O_2}) *via* hepatic venous catheters have been reported previously.[3,4] Although successfully used in research settings,[5–7] this technique is not used clinically, presumably because the measurement is not continuous and because anesthesiologists are unaccustomed to the hepatic venous catheterization in humans. Fiberoptic technology used in pulmonary artery (PA) catheters now permits monitoring of mixed venous oxygen saturation ($S\bar{v}_{O_2}$), which can serve as a continuous indicator of the adequacy of cardiopulmonary function during anesthesia.[8] If the same technique is applied to the liver, Shv_{O_2} should provide minute-to-minute information of hepatic oxygen supply–demand ratio during anesthesia in patients with impaired liver function.[9] Using such a catheter in a series of patients undergoing liver surgery, we cannulated the hepatic vein (HV) prior to anesthetic induction in the operating room and evaluated the safety and efficacy of continuous monitoring of Shv_{O_2} as part of anesthetic management.

Materials and Methods

We studied 33 consecutive adult patients (25 men and 8 women) undergoing elective hepatic lobectomy for either hepatocellular or biliary tract tumor. Their average age was 58 yr (range 49–73), height 161 cm (range 148–176), and weight 57 kg (range 49–78). The study was approved by the institutional human research committee, and informed consent was obtained from each patient. Thirteen patients had liver cirrhosis confirmed by postoperative microscopic examination. All patients had routine preoperative laboratory tests including complete blood cell count, serum electrolytes, liver function, urinalysis, electrocardiogram (ECG), and chest x-ray. Abdominal angiography including selective hepatic venography was performed for preoperative evaluation of the liver tumor. Patients received 0.5 mg atropine sulfate and 50 mg hydroxyzine hydrochloride intramuscularly prior to transport to the operating room. A cannula was inserted into the radial artery for monitoring systemic arterial pressure (SAP) and 50–100 μg fentanyl was administered through a peripheral venous cannula.

HV catheterization was performed with continuous monitoring of ECG, radial arterial blood pressure, and pulse oximetry. First, a 16-G cannula was inserted into the right internal jugular (IJ) vein after infiltration of the skin with 2–4 ml 1% lidocaine. A guide wire was inserted through the cannula, and then the catheter was withdrawn. Another 16-G cannula was then inserted into the same IJ vein 1–2 cm cephalad or caudal to the first puncture site, and a guide wire inserted. An 8-Fr dilator-sheath unit (Arrow, Reading, PA) was threaded over either of two guide wires. A 7-Fr fiberoptic PA catheter (Opticath model P7110-EH, Oximetrix, Mountain View, CA) was placed in the right (n = 13), middle (n = 7), or left HV (n = 13) under fluoroscopic guidance. Two milliliters 30% iopamidol was infused through the catheter to confirm its positioning by referring to preoperative selective hepatic venography. The catheter was withdrawn 1.5 cm from the wedged position and fixed to the skin after the sheath was totally withdrawn. Another dilator-sheath unit was then placed over the second guide wire for PA catheterization. Fluoroscopy was repeated to confirm placement of both catheters and to confirm absence of coiling.

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Anesthetic induction and tracheal intubation were accomplished with 5 mg/kg thiamylal sodium and 1 mg/kg succinylcholine supplemented with 4 μg/kg fentanyl. Anesthesia was maintained with 67% nitrous oxide and oxygen with 1–2% enflurane. Ventilatory settings were adjusted to maintain Pa_{CO_2} between 35 and 40 mmHg. In addition, hepatic venous pressure was monitored continuously to detect inadvertent wedging of the HV catheter during surgery. The HV catheter was removed immediately after surgery or in the morning of the first postoperative day. $S\bar{v}_{O_2}$, Shv_{O_2}, and other hemodynamic variables were continuously recorded. Values before and after anesthetic induction were taken when Shv_{O_2} readings were stable. Values after skin incision were taken when Shv_{O_2} showed the lowest value during the period between skin incision and laparotomy.

$S\bar{v}_{O_2}$, Shv_{O_2}, and other hemodynamic variables were presented as mean ± SD values. Repeated-measures analysis of variance was used to evaluate time course changes in each value, and Dunnett's test to compare individual means with the value before anesthetic induction. The unpaired *t* test was used to assess differences of time required for HV catheterization, Shv_{O_2} values among three HVs, and hemodynamic variables in patients with and without cirrhosis. In addition, the relationship between $S\bar{v}_{O_2}$ and Shv_{O_2} was analyzed by simple linear regression, and the correlation coefficient was calculated by the least-squares method. A *P* value of 0.05 or less was considered significant.

Results

The average time required for the HV catheterization, from calibration of oxygen saturation equipment to catheter suturing, was 13.9 min. There were no significant differences in the time required to place catheters in the right, middle, or left HV. In all patients, both catheters were placed successfully, without hemodynamic derangement or patient discomfort. The complication observed was atrial and (rarely) ventricular premature contractions as the catheter was advanced from the right atrium (RA) to the inferior vena cava (IVC).

TABLE 1. $S\bar{v}_{O_2}$, Shv_{O_2}, and Other Hemodynamic Variables before and after Anesthetic Induction and after Skin Incision

	Total (n = 33)	Cirrhosis (−) (n = 20)	Cirrhosis (+) (n = 13)
Before anesthetic induction			
$S\bar{v}_{O_2}$ (%)	74 ± 4	73 ± 4	76 ± 4
Shv_{O_2} (%)	67 ± 10	67 ± 11	66 ± 8
MAP (mmHg)	90 ± 11	92 ± 12	88 ± 9
MPAP (mmHg)	14 ± 4	14 ± 4	15 ± 4
PAWP (mmHg)	7 ± 3	6 ± 3	9 ± 3†
CVP (mmHg)	5 ± 3	5 ± 3	6 ± 2
CO (l/min)	5.6 ± 1.4	5.3 ± 1.0	6.0 ± 1.7
HR (beats per min)	82 ± 15	84 ± 16	79 ± 14
After anesthetic induction			
$S\bar{v}_{O_2}$ (%)	77 ± 9	76 ± 11	79 ± 5
Shv_{O_2} (%)	70 ± 17	68 ± 18	73 ± 16
MAP (mmHg)	79 ± 15*	78 ± 15*	81 ± 14*
MPAP (mmHg)	15 ± 5	16 ± 5	14 ± 4
PAWP (mmHg)	7 ± 3	7 ± 3	7 ± 2
CVP (mmHg)	5 ± 3	5 ± 3	6 ± 3
CO (l/min)	5.2 ± 1.2	5.0 ± 1.0	5.4 ± 1.4
HR (beats per min)	80 ± 16	82 ± 16	77 ± 13
After skin incision			
$S\bar{v}_{O_2}$ (%)	79 ± 7	78 ± 7	80 ± 6
Shv_{O_2} (%)	53 ± 23*	49 ± 25*	59 ± 18*
MAP (mmHg)	92 ± 14	94 ± 13	90 ± 14
MPAP (mmHg)	19 ± 5*	19 ± 5*	20 ± 5*
PAWP (mmHg)	10 ± 4*	9 ± 3*	12 ± 4*,†
CVP (mmHg)	7 ± 3	6 ± 3	7 ± 3
CO (l/min)	6.1 ± 1.5	6.3 ± 1.6	5.9 ± 1.3
HR (beats per min)	91 ± 14	90 ± 15	91 ± 12

Values are mean ± SD.

Cirrhosis (−) = without liver cirrhosis; cirrhosis (+) = with liver cirrhosis; $S\bar{v}_{O_2}$, mixed venous oxygen saturation; Shv_{O_2} = hepatic venous oxygen saturation; MAP = mean arterial pressure; MPAP = mean pulmonary arterial pressure; PAWP = pulmonary artery wedge pressure; CVP = central venous pressure; CO = cardiac output; HR = heart rate.

* $P < 0.05$ as compared with the value before anesthetic induction.

† $P < 0.05$ as compared with patients with cirrhosis (−).

Shv_{O_2} showed no significant differences among three HVs before anesthetic induction. Anesthetic induction did not alter $S\bar{v}_{O_2}$ and Shv_{O_2}. However, skin incision was followed by a significant decrease in Shv_{O_2} not reflected in $S\bar{v}_{O_2}$ (table 1). Surgical manipulation of the liver, separation of the hepatic artery or portal vein from the surrounding tissues, and cross-clamping of hepatic inflow also induced a marked decrease in Shv_{O_2} (fig. 1). Eighteen patients showed decreases in Shv_{O_2} to less than 30%; the total duration of these decreases ranged between 2 and 55 min. Whenever Shv_{O_2} reached a value of less than 30% that presumably was due to surgical manipulation, we informed the surgeons. Minor modification of the surgical procedure often increased Shv_{O_2}. There was no significant difference between patients with and without cirrhosis in Shv_{O_2} at any time during surgery.

Discussion

HV catheterization is performed when either hepatic venography or measurement of intrahepatic sinusoidal pressure is needed.[10,11] The method of choice is a retrograde cannulation of the HV through the basilic or femoral vein. However, Hanafee and Weiner[12] recommended the IJ vein approach because of its direct anatomic access to the HV *via* the superior vena cava, RA, and IVC. The IJ vein approach is useful for anesthesiologists because it permits inspection of the cannulation site throughout the surgical procedure.[13] One problem reported when two catheters are inserted into the same vein is laceration or transection of the first catheter by the second needle puncture.[14] This complication can be avoided by placing a guide wire alone when the second needle is inserted. Occasionally, atrial premature contractions are induced when the curved tip of the HV catheter contacts the RA wall instead of advancing into the IVC. We found that straightening the (normally curved) catheter facilitated catheterization without complications. When the catheter repeatedly contacted the RA wall, we found it better to withdraw it completely and repeat the attempt at passage. Ventricular arrhythmias were rare events in our series, unlike other reports describing PA catheterization.[15] Preoperative hepatic venography is useful to identify the anatomy of the HV and to help confirm correct placement of HV catheters. This procedure can also be accomplished without venography, however, because the anatomy of the HV is relatively constant except in patients with large hepatic tumors.[16,17] Time required for HV catheterization was a little greater than that for PA catheterization.[18]

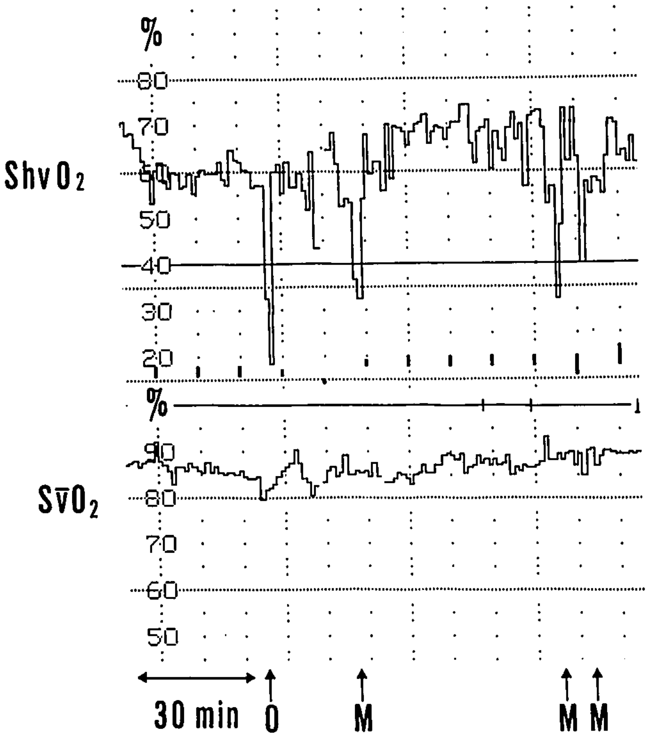

FIG. 1. An example of Shv_{O_2} and $S\bar{v}_{O_2}$ recordings during temporary occlusion of the hepatic artery and portal vein and subsequent surgical manipulation of the liver. O = temporary occlusion of the hepatic artery and portal vein; M = surgical manipulation of the liver.

Another potential complication is thrombus formation along the catheter,[19,20] although there was no evidence of this complication in our cases. The outer surface of the PA catheter used in this study was heparin-coated, and heparin was infused continuously at a rate of 18 U/h. The diameter of the HV may be another factor contributing to development of thrombosis. Currently we are designing a smaller-diameter oximeter catheter modeled from an umbilical artery optical catheter (model U425, Oximetrix).

Shv_{O_2} represents a summation of hemoglobin oxygen saturation in the blood at the venous ends of all sinusoids in the liver,[9] just as $S\bar{v}_{O_2}$ is a summation of hemoglobin oxygen saturation in blood drained from all tissues. In our patients, Shv_{O_2} bore little relationship to $S\bar{v}_{O_2}$, as seen in figure 2. Shv_{O_2} levels in our patients without cirrhosis were similar to those reported in one prior study.[21] In that study, patients with cirrhosis showed decreased hepatic venous oxygen tension with unchanged splanchnic oxygen uptake, when compared to patients without cirrhosis. On the other hand, Cohn *et al.*[22] observed that Shv_{O_2} increased and splanchnic oxygen uptake decreased when alcoholic hepatitis proceeded to liver cirrhosis with coma. Thus, Shv_{O_2} may vary with the degree of progression of cirrhosis and its etiology.

A decrease in Shv_{O_2} after skin incision may be associated with a significant reduction in the estimated HBF. Stimulation of the sympathetic nervous system or hepatic adrenergic receptors may be involved, although this possi-

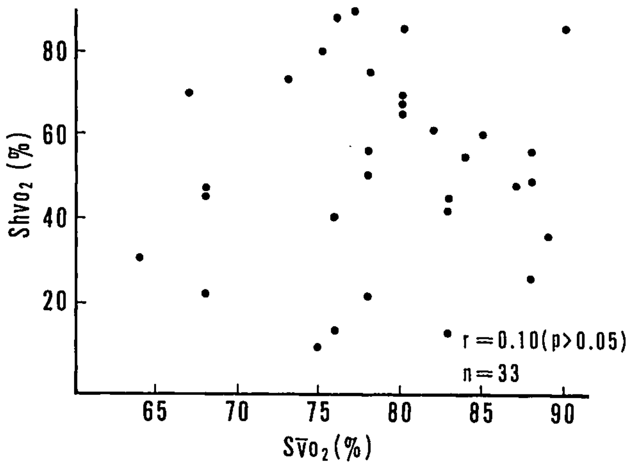

FIG. 2. Lack of relationship between mixed venous and hepatic venous hemoglobin oxygen saturations after skin incision.

bility has not been investigated specifically. A marked decrease in Shv_{O_2} frequently was observed concomitant with surgical compression of the liver, vascular separation of the hepatic hilus, and temporary cessation of the total hepatic inflow. Decreases in hepatic venous oxygen tension below 5–10 mmHg in cats[23] or 14 mmHg in dogs[24] reportedly produced hepatic dysfunction. Although it remains to be investigated which level of Shv_{O_2} is related to hepatic dysfunction in humans, we assume that an Shv_{O_2} of less than 30% may be detrimental to liver function.

By monitoring both $S\bar{v}_{O_2}$ and Shv_{O_2}, we were able to respond to a decrease in Shv_{O_2} and adjust patient management to improve this value.

In conclusion, we have demonstrated that hepatic venous cannulation and continuous monitoring of Shv_{O_2} is practical in patients undergoing hepatic surgery. The ultimate clinical usefulness of Shv_{O_2} monitoring must await more complete studies in patients with normal and abnormal hepatic function.

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