Hemodynamic and Oxygen Delivery-Consumption Changes during Partial Liver Resection

Hideo IWASAKA, Takaaki KITANO, Akio MIZUTANI, Kazuo TANIGUCHI, Natsuo HONDA, Yang I. KIM* and Michio KOBAYASHI*

The effects of partial liver resection on hemodynamics and the oxygen delivery-consumption relationship were evaluated in ten patients with hepatocellular carcinoma. The cardiac index and oxygen delivery were increased significantly ($P < 0.05$) at 30 minutes after incision, 30 min after liver resection and in the recovery room. Oxygen delivery decreased significantly ($P < 0.05$) during liver resection. Oxygen consumption remained low throughout the procedure. We did not discover any flow-dependent change in oxygen consumption. Although our patients persisted a hyperdynamic state throughout surgery, their arterial ketone body ratio remained low. Therefore, it may be necessary to maintain a hyperdynamic state during partial liver resection in order to increase hepatic blood flow. (Key words: oxygen delivery, oxygen consumption, partial liver resection)

(Iwasaka H, Kitano T, Mizutani A, et al.: Hemodynamic and oxygen delivery-consumption changes during partial liver resection. J Anesth 7: 145–150, 1993)

Elevated cardiac output with increased heart rate and decreased systemic vascular resistance are common cardiovascular changes in patients with chronic liver dysfunction, especially hepatocellular carcinoma and liver cirrhosis. Furthermore, oxygen consumption remains in the low normal range until the preterminal phase. There are many animal experiments which show that acute occlusion of the portal vein results in rapid cardiovascular collapse[1,2], as the liver is generally believed to be highly susceptible to anoxic damage. However, it is agreed that the liver can tolerate normothermic ischemia for an hour or more[3,4]. These findings account for the frequent use of temporary hepatic inflow occlusion performed by cross-clamping both the portal vein and the hepatic artery during major liver surgery. Oxygen consumption, although studied well in experimental animals and shock patients, has only recently become the subject of study in liver transplantation. The present study was performed to investigate the intraoperative changes in hemodynamics and the oxygen supply-demand relationship

Department of Anesthesiology and 1st Department of Surgery, Oita Medical University, Oita, Japan*

Address reprint requests to Dr. Iwasaka: Department of Anesthesiology, Oita Medical University, 1-1, Idaigaoka, Hasama-machi, Oita-gun, Oita, 879-55 Japan

Table 1. Hemodynamic effects of liver resection surgery

	①	②	③	④	⑤
Heart Rate ($beat \cdot min^{-1}$)	74.6±3.1	90.2±5.2*	93.0±4.1**	94.6±4.5**	83.0±3.7
Systolic Arterial Pressure (mmHg)	104.4±3.0	126.6±4.2***	119.4±2.2**	116.6±4.4**	122.6±3.5**
Diastolic Arterial Pressure (mmHg)	57.7±3.2	73.8±3.8***	69.6±2.1**	64.0±2.6	67.0±0.4
Mean Arterial Pressure (mmHg)	73.0±3.1	91.4±3.7***	86.2±1.9**	81.6±2.7	85.5±3.8**
Oxygen Contents ($ml \cdot dl^{-1}$)	15.5±0.7	16.3±0.7	15.9±0.4	14.8±0.5	15.0±0.7
Cardiac Index ($l \cdot min^{-1} \cdot m^{-2}$)	2.81±0.28	3.69±0.16*	3.05±0.16	4.19±0.28***※	3.94±0.33**※
Blood Glucose ($g \cdot dl^{-1}$)	142.2±10.5	176.7±17.5	210.6±11.1*	219.5±15.7***	215.6±18.6**
AKBR	0.76±0.14	0.60±0.18	0.47±0.19	0.69±0.19	0.68±0.13

Values are means±SE,

*$P < 0.05$ when compared with ①
**$P < 0.01$ when compared with ①
***$P < 0.001$ when compared with ①
※$P < 0.05$ when compared with ③

①; 30 minutes after anesthesia induction, ②; 30 min. after incision, ③; during liver resection, ④; 30 min. after liver resection, ⑤; recovery room

in patients who undergo partial liver resection.

Subjects and Methods

The study was approved by the Institutional Board for Ethics Committee. Informed consent was obtained from ten patients (mean weight, 63.7 kg; mean body surface area, 1.67 m^2) scheduled for partial liver resection due to hepatocellular carcinoma. Their ages ranged from 55 to 72 and averaged 62 yrs. Their mean preoperative Indocyanine green excretion at 15 minutes was 21.5 ± 3.6 percent (range, 9.6 to 39). Every patients was premedicated with diazepam and atropine. Anesthesia was induced with thiamylal sodium (4–5 $mg \cdot kg^{-1}$) and vecuronium bromide (0.1–0.15 $mg \cdot kg^{-1}$) was given for muscle relaxation. Anesthesia was maintained with isoflurane (1.0–2.0%), vecuronium bromide and endotracheal 60% nitrous oxide in oxygen. Ventilation was controlled throughout anesthesia. Cardiovascular parameters that were monitored included heart rate and radial artery pressure. After induction, a thermodilution catheter (Arrow international, Inc., AH-05100H) was inserted via the right internal jugular vein to measure cardiac output (CO) and mixed venous oxygen content. Oxygen contents were measured by Hemoximeter (Radiometer Inc.). Oxygen consumption and delivery were calculated at each of the following five specific time periods

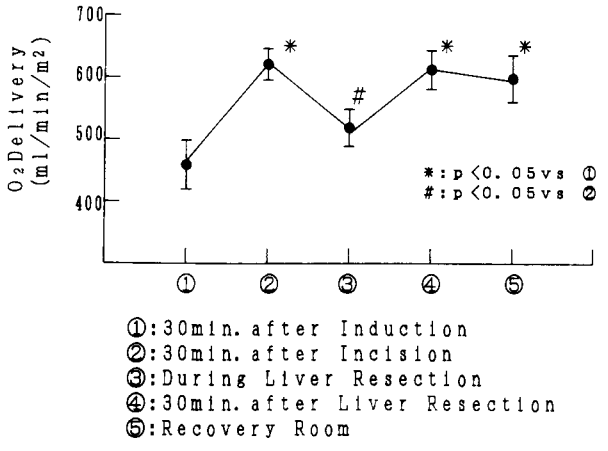

Fig. 1. The changes of oxygen delivery. Data presented are mean ± SE.

using the Fick equation, where:

Cardiac index (CI) = CO × BSA^{-1},

Oxygen delivery index ($\dot{D}_{O_2}$) = CI × arterial oxygen content, and Oxygen consumption index ($\dot{V}_{O_2}$) = CI × (arterial oxygen content − mixed venous oxygen content).

Ketone body levels were measured enzymatically by Williamson's method[5] using a spectrophotometer (Keto 340, Ihara-denshi Co., Ltd.). The arterial ketone body ratio (AKBR) was specified as the ratio of the acetoacetate to the hydroxybutyrate level. Blood was sampled and hemodynamic measurements were made during each of the following five peridos: (1) 30 min after anesthesia induction, (2) 30 min after incision, (3) during liver resection while both the hepatic artery and portal vein were cross-clamped, (4) 30 min after liver resection, and (5) in the recovery room.

The mean hepatic artery and portal vein clamp time was 54.3 ± 3.9 min. During liver ischemia, the mean body temperature was 35.6 ± 0.3°C. Data were compared statistically by Student's t-test and ANOVA. Statistical significance was set at $P < 0.05$. All data are presented as the mean ± standard error.

Results

Hemodynamic parameters, blood glucose level, oxygen content, and the arterial ketone body ratio are reported in the table 1. At 30 min after anesthesia induction, the cardiac index was 2.80 ± 0.28 $l \cdot min^{-1} \cdot m^{-2}$ but increased ($P < 0.05$) within 30 min after incision and remained so at after liver resection and in the recovery room. During liver resection, the cardiac index was higher than that at 30 min after anesthesia induction. The blood oxygen content remained constant throughout surgery. At 30 min after anesthesia induction, the arterial ketone body ratio was 0.76 ± 0.14. Although not statistically significant, the AKBR decreased to its lowest (0.47) during liver resection. Afterward, the AKBR increased gradually, even while in the recovery room. We also measured the AKBR on the first postoperative day in five patients, and found their AKBR to exceed 1.0.

The oxygen delivery and consumption data are shown in figures 1 and 2. At 30 min after anesthesia induction, oxygen delivery was 459 ± 39 $ml \cdot min^{-1} \cdot m^{-2}$, and increased ($P < 0.05$) within 30 min after the incision was made, at 30 min after liver resection, and in the recov-

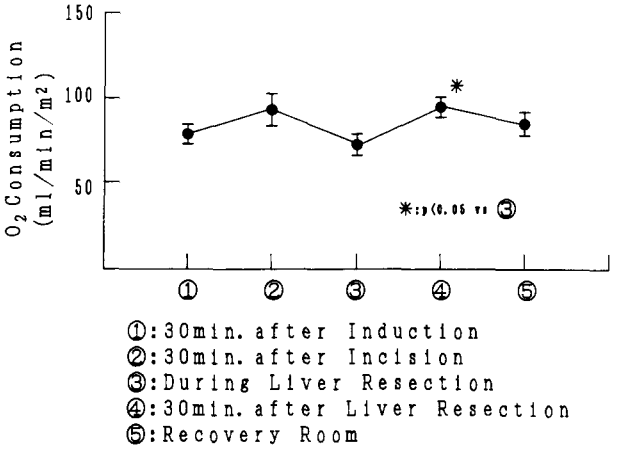

Fig. 2. The changes of oxygen consumption. Data presented are mean ± SE.

ery room. Oxygen delivery was lower ($P < 0.05$) during liver resection when compared to that at 30 min after incision. Changes in oxygen delivery varied with the cardiac index. However, the initial oxygen consumption was 79.1 ± 5.8 ml·min^{-1}·m^{-2}, and increased ($P < 0.05$) compared to that during liver resection within 30 min after liver resection to 95.1. We could not find any linear oxygen supply-demand relationship during surgery. Therefore, there is no flow dependent increase in oxygen consumption during liver resection.

Discussion

The ten patients with hepatocellular carcinoma reported here experienced singnificant changes in cardiac index and oxygen delivery during liver resection surgery, while their oxygen consumption was stable. The cardiovascular effects of temporarily clamping both the hepatic artery and portal vein have not been studied well in animals or humans. Delva et al. described the hemodynamic effects of portal triad clamping in humans[8]. They reported that combined occlusion of the portal vein and hepatic artery induces a mild decrease in cardiac output associated with a small decrease in ventricular filling pressure increasing the arterial pressure and increasing markedly the systemic vascular resistance. In the present, we too observe a similar result. Although the present study did not revealed the mechanisms underlying the observed decrease in the cardiac index, hypovolemia caused by splanchnic sequestration is most likely cause[7]. Other mechanisms involving a hormone or cardiopulmonary reflex activation are also possible. Oka et al. indicated that the decrease in blood pressure observed during portal vein occlusion did not result from a decrease in myocardial contractility but rather, from a reduction in preload[8].

The plasma glucose level is known to an early marker of graft non-function in liver transplantation[9]. Our patients exhibited a trend toward mild elevation of glucose levels. However, none of our patients had a markedly elevated glucose level which might have indicated after unclamping liver dysfunction.

Under isoflurance anesthesia, oxygen consumption by our group of patients was less than the normal values reported for other isoflurane anesthetized patients (130 vs 173 ml·min^{-1})[10]. In the present study, every patient was also hypothermic (35.6°C) and had almost the same weight. We could not determine any

difference in body temperature or weight among patients which was sufficient to explain the discrepancy in basal metabolic rate. In patients with liver dysfunction, the total body metabolism is depressed[11]. There are several reasons why their metabolic rate may be low. Five of our patients had cirrhotic hepatocellular carcinoma. The cirrhotic liver is less responsive to insulin. Therefore, glucose uptake, gluconeogenesis, and metabolism are depressed. Furthermore, the hepatic conversion of thyroid hormone is reduced, and protein production, an energy consuming process, is depressed[12]. Therefore, depressed total body metabolism, which is evident as decreased oxygen consumption by liver dysfunction patients, may be due largely to depressed hepatic carbohydrate and protein metabolism. Generally, in circulatory failure patients it has been demonstrated that increased oxygen delivery which corresponds to an increase in oxygen consumption results in higher blood lactate levels, a marker of anaerobic metabolism[12]. Although oxygen consumption was lower in our group than in other anesthetized patients, we could not discern any linear oxygen supply-demand relationship. We conclude, therefore, that this decrease in whole body oxygen consumption is caused by the liver dysfunction itself, not by circulatory insufficiency under anesthesia. At 30 min after liver resection, oxygen consumption increased compared to that during liver resection. This increase may have been caused by recirculation to the liver after unclamping, such that metabolism by the liver itself was solely responsible for the observed increase in whole body oxygen consumption.

The energy charge, which is expressed as (ATP + 1/2 ADP)/(ATP + ADP + AMP), depends upon the differences between energy-yielding and energy-utilizing reactions in a metabolic pool. Ozawa et al.[14,15] studied the clinical significance of the arterial ketone body ratio as an indicator of hepatocyte energy status. They said that ketone body ratio in hepatocytes is in equilibrium with oxidized and reduced forms of free nichotinamide-adenine dinucleotides in their mitochondria. They also demonstrate that changes in the ratio of acetoacetate to β-hydroxybutyrate in the arterial blood may be used clinically as an accurate indicator of the energy level in the remnant liver after liver resection. In our study, AKBR was at its lowest during liver resection and, thereafter, recovered gradually. Therefore, even if whole body oxygen consumption is lower than normal, it would be better to increase oxygen delivery so as to maintain the energy level in the remnant liver. This may improve the postoperative prognosis.

Although the cardiac index changed during surgery, we could not discern any relationship to flow of oxygen consumption during liver resection surgery. Oxygen delivery remained high, compared to that after anesthesia induction, throughout surgery. Oxygen demand, however, was stable during surgery. We conclude, therefore, that oxygen delivery was sufficient to meet the requirement of the entire body. It may be useful to augment the hyperdynamic state during partial liver resection surgery, because the arterial ketone body ratio remains low during the operation.

(Received Jun. 6, 1992, accepted for publication Jul. 9, 1992)

References

1. Raffuchi FL: The effects of temporary occlusion of the afferent hepatic circulation in dogs. Surgery 33:342–346, 1953
2. Beach PM, Toress E, Litton A: Acute occlusion of the portal vein in dogs. Surg Gynec Obst 121:761–766, 1965

3. Huguet C, Nordlinger B, Bloch P, et al: Tolerance of the human liver to prolonged normothermic ischemia. Arch Surg 113:1448–1451, 1978
4. Nordlinger B, Douvin D, Javaudin L, et al: An experimental study of survival after two hours of normothermic hepatic ischemia. Surg Gynec Obst 150:859–864,1980
5. Williamson DH, Mellandy J, Krebs HA, et al: Enzymic determination of D-(−)-β-hydroxybutyric acid and acetoacetic acid in blood. Biochem J 82:90–96, 1962
6. Delva E, Camus Y, Paugam C, et al: Hemodynamic effects of portal triad clamping in humans. Anesth Analg 66:864–868, 1987
7. Alexander RS, Edwards WS, Ankeny JL: The distensibility characteristics of the portal vascular bed. Circ Res 1:271–277, 1953
8. Oka T, Ohwada T, Mizuguchi T, et al: Effects of portal vein occlusion, myocardial contractility. J Anesth 5:344–351, 1991
9. Mallett S, Kang Y, Freeman J, et al: Prognostic significance of reperfusion hyperglycemia during liver transplantation. Anesth Analg 68:182–185, 1989
10. Ciofolo MJ, Clerque F, Delvilhiers C, et al: Changes in ventilation, oxygen uptake, and carbon dioxide output during recovery from isoflurane anesthesia. Anesthesiology 70:737–741, 1989
11. Spiess BD, Tuman KJ, McCarthy RJ, et al: Oxygen consumption and mixed venous oxygen saturation monitoring during orthotopic liver transplantation. J Clin Monit 8:7–11, 1992
12. Van Thiel DA: The liver and endocrine system. The liver: biology and pathology. Edited by Arias IM, Popper H, Schachter D, et al. New York, Raven, 1988, pp. 1007–1031
13. Haupt MT, Gilbert EM, Carlson RW: Fluid loading increases oxygen consumption in septic patients with lactic acidosis. Am Rev Respir Dis 131:912–916, 1985
14. Ozawa K, Fujimoto T, Nakatani T, et al: Changes inhepatic energy charge, blood ketone body ratio, and Indocyanine green clearance in relation to DNA synthesis after hepatectomy. Life Sci 31:647–653, 1982
15. Tanaka J, Ozawa K, Tobe T: Significance of blood ketone body ratio as an indicator of hepatic cellular energy status in jaundiced rabbits. Gastroenterol 76:691–969, 1979