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Laparoscopic insufflation of the abdomen reduces portal venous flow

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Abstract
Background: The adverse effects of sustained elevated intraperitoneal pressure (IPP) on cardiovascular, pulmonary and renal systems have been well documented by several reported experimental and clinical studies. Alteration in the splanchnic circulation has also been reported in animal experiments, but details of the exact hemodynamic changes in the flow to solid intraabdominal organs brought on by a raised intraperitoneal pressure in the human are not available. The aim of the present study was to estimate effect of increased IPP on the portal venous flow, using duplex Doppler ultrasonography in patients undergoing laparoscopic cholecystectomy.
Methods: The studies were performed using the SSD 2000 Multiview Ultrasound Scanner and the UST 5536 7.0-MHz laparoscopic transducer probe. Details of the measurements were standardized in according to preset protocol. Statistical evaluation of the data was conducted by the two-way analysis of variance (ANOVA).
Results: The flow measurement data have demonstrated a significant ($p < 0.001$) decrease in the portal flow with increase in the intraperitoneal pressure. The mean portal flow fell from 990 ± 100 ml/min to 568 ± 81 ml/min (−37%) at an IPP of 7.0 mmHg and to 440 ± 56 mmHg (−53%) when the IPP reached 14 mmHg.
Conclusions: The increased intraperitoneal pressure necessary to perform laparoscopic operations reduces substantially the portal venous flow. The extent of the volume flow reduction is related to the level of intraperitoneal pressure. This reduction of flow may depress the hepatic reticular endothelial function (possibly enhancing tumor cell spread). In contrast, the reduced portal flow may enhance cryoablative effect during laparoscopic cryosurgery for metastatic liver disease by diminishing the heat sink effect. These findings suggest the need for a selective policy, low pressure or gas-less techniques to positive-pressure interventions, during laparoscopic surgery in accordance with the disease and the therapeutic intent.

Key words: Laparoscopic surgery — Pneumoperitoneum — Portal venous volume flow — Intraoperative duplex sonography — Laparoscopic ultrasonography

Laparoscopy has been for many decades used mainly for diagnosis and in the conduct of minor gynecological operations. The advent of laparoscopic cholecystectomy demonstrated the advantages of minimal access surgery (MAS) to the general surgeons who have since adopted the laparoscopic approach and extended it to include many other operations. Procedures such as laparoscopic antireflex operations, splenectomy, colonic resections, etc., are now established, but because of the insufflation of the peritoneal cavity necessary to obtain the endoscopic exposure, these patients are being subjected to an artificially elevated intraperitoneal pressure (IPP) for several hours. The adverse effects of this elevated IPP on the systemic circulation and cardiac, pulmonary, and renal functions have been well documented in experimental and clinical studies [4–6, 9, 13, 14]. In addition, changes in the splanchnic circulation such as decreased mucosal blood flow have been reported in animal experiments but, to date, information on the effect of a sustained elevated IPP on the flow to the solid intraabdominal organs in the human has been lacking. The present study was undertaken to quantitate the effect of increased IPP on the portal venous flow in patients undergoing laparoscopic cholecystectomy using duplex Doppler ultrasonography.

Material and methods

Portal venous volume flow measurements were performed in 11 consecutive patients (seven female, four males) undergoing routine uncomplicated laparoscopic cholecystectomy. The mean age of the patients included in the study was 45 years, (range 26–76 years). Measurements were performed in accordance with a preset protocol in a standardized way by the same investigator with longstanding experience in laparoscopic and duplex

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Table 1. Blood volume flow measurement—available techniques[a]

Electromagnetic (i)
Ultrasound flowmetry (i)
Magnetic resonance angiography (MRA)
CVI-Q (time domain correlation)
Duplex Doppler ultrasound

[a] (i) invasive.

Doppler ultrasonography. The visual clues from the color Doppler flow imaging were used for exact plotting of the Doppler samples from areas of bloodstream with a luminal flow pattern. The ultrasound system was operated and the measurements registered by the same technician.

The same balanced general anesthesia was used in all the patients who were ASA class I or II and premedication was with diazepam, 10 mg, orally. Anesthesia was induced with propofol 2.5 mg kg^{-1} and fentanyl 3 $\mu g\ kg^{-1}$. Tracheal intubation was accomplished after administration of vecuronium bromide 0.1 mg kg^{-1}. A temporary nasogastric tube was inserted. Anesthesia was maintained with propofol delivered by infusion pump 6–10 mg $kg^{-1}\ h^{-1}$ with increments of IV fentanyl or relaxants when necessary.

Patients were ventilated with a 40% oxygen/air mixture. The end-tidal expired CO_2 was kept between 4 and 5 vol %. During abdominal CO_2 insufflation an end-tidal CO_2 of 5–6 vol % was accepted. The propofol infusion was stopped 5 min before the completion of surgery when the neuromuscular blockade was reversed with neostigmine and atropine. Monitoring during surgery consisted of heart rate, ECG, pulse oximetry, and automatic noninvasive blood pressure.

None of the patients included in the study required central venous pressure or Swan-Ganz catheter monitoring, which could have provided additional information on the circulatory state of the patient during the ultrasound measurements. However, it should be stressed that continuous monitoring of pulse rate and blood pressure during the entire period of anesthesia and during the flow measurements showed a stable circulatory state in all the patients included in the study.

Portal flow measurements were conducted with the patients in the horizontal position. The transducer probe was introduced through the umbilical access port and then placed on the hepatoduodenal ligament. The anatomic landmarks provided by the structures displayed on the B-mode ultrasound image were used as guidance throughout the flow measurements.

The ultrasound system used has the ability to calculate and display the volumetric flow. This is derived as follows. The blood vessel of interest (in this case the portal vein) is imaged using the pulse echo system. The Doppler system calculates the mean velocity of the flow in the direction of the echo-receiving transducer. Indicating the direction of the blood flow in the image allows the angle θ between the ultrasound beam axis and vessel axis to be known to the system. Thus, the mean velocity parallel to the vessel axis can be calculated. This value is multiplied by the cross-sectional area of the vessel to yield the mean flow (Q).

The time-averaged volumetric flow Q through a vessel is given by the time-averaged product of the cross-sectional area of the vessel $A(t)$ and the mean velocity of the blood within the vessel $v(t)$:

$$\overline{Q} = \frac{1}{T_{t=0}} \int^{T} A(t)\ \overline{v}(t) dt \qquad (1)$$

The vessel cross section area is calculated after marking the vessel diameter in the image and assuming the vessel to be circular in cross section.

The mean velocity can be calculated using the standard Doppler equation:

$$\overline{v}(t) = \frac{\overline{f}_d(t)\ c}{2\ f_t \cos(\theta)} \qquad (2)$$

Where $f_d(t)$ is the instantaneous mean Doppler shift, c the velocity of ultrasound in blood, f_t the transmitted frequency, and θ the angle between the axis of the ultrasound beam and the vessel axis. Substitution of equation 2 in equation 1 yields:

$$\overline{Q} = \frac{c}{2 f_t \cos(\theta)_{t=0}} \int^{T} \frac{A(t) \overline{f}_d(t)}{T} dt \qquad (3)$$

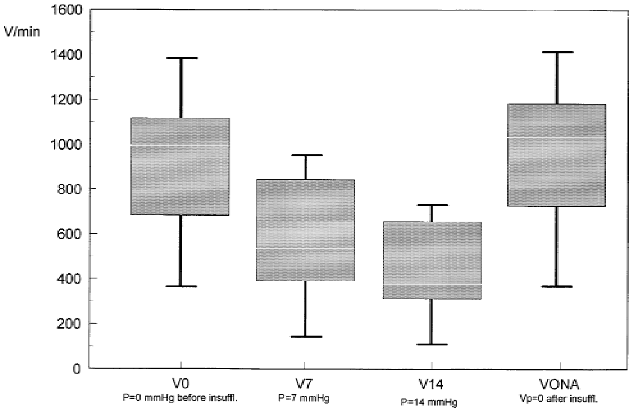

Fig. 1. Effect of IPP changes on portal venous flow.

In the method used changes of the diameter with time were not taken into account, so equation 3 finally can be written as:

$$\overline{Q} = \frac{cA}{2 f_t \cos(\theta)_{t=0}} \int^{T} \frac{\overline{f}_d(t)}{T} dt \qquad (4)$$

Values of A and θ are obtained by caliper (marker) setting, performed by the investigator; f_t is the ultrasound frequency used, and c is the constant value of ultrasound in blood. This is the basic for the calculation of the volumetric flow Q, using the Doppler shift frequency f_d.

The data before and after insufflation were analyzed by the two-way analysis of variance (ANOVA) for repeated measurements.

Results

The changes in the portal flow observed at different pressure levels of 0, 7, and 14 mmHg are outlined in Fig. 1.

A rise of the IPP to 7 mmHg was accompanied by a reduction of the mean portal flow from 990 ± 100 ml/min to 568 ± 81 ml/min, i.e., a 37% decrease of the flow comparing to the baseline flow measured at 0 mmHg pressure. At an IPP level of 14 mmHg, which is used routinely in our department for all laparoscopic procedures, the portal venous flow sustained a further drop to 440 ± 56 mmHg, corresponding to 53% reduction of the portal venous flow compared to the initial baseline value. The portal venous flow was measured again following desufflation of the abdomen to 0 mmHg. These values were similar to those obtained at the start of the procedure ($p = 0.20$, t-test). These data indicate the existence of a correlation between the level of intraperitoneal pressure and portal venous flow.

Discussion

The introduction and spread of minimal access surgery (MAS) stimulated many investigators to study the potential adverse effects of increased IPP on systemic circulation, respiratory function, and the splanchnic circulation. These adverse effects on cardiac, pulmonary, and renal function have been confirmed by several studies [4–6, 9, 13, 14].

In addition to IPP, other factors may induce cardiovascular changes during laparoscopy, e.g., volume of the CO_2 absorbed, the patient's intravascular volume, patient's position, the technique of ventilation during anesthesia, and the drugs administered during the procedure.

The effect of increased IPP caused by insufflation of carbon dioxide evokes changes in systemic hemodynamics, such as increase of mean arterial blood pressure and systemic vascular resistance. Limited nonsignificant changes in the central venous pressure and cardiac index have been reported by different investigators [5, 12]. However, studies with Swan-Ganz catheter monitoring during laparoscopic cholecystectomy have failed to demonstrate any significant change in cardiac output, pulmonary arterial pressure, and pulmonary arterial wedge pressure [7] when the IPP pressure was set at 10 mmHg. In the present study we had no sufficient justification to add these invasive monitoring procedures to the study protocol.

The changes in the systemic circulation are influenced by the hemodynamic state of the abdominal viscera, which requires a substantial part of the circulating blood volume. It may be assumed that changes observed in splanchnic hemodynamics are induced both by the pharmacological effects of carbon dioxide and also by mechanical compression due to the raised intraperitoneal pressure. At the time the current study was initiated there were limited data on hemodynamic changes in the blood supply to the solid intraabdominal organs.

Laparoscopic duplex ultrasonography provides a noninvasive method of volume flow measurement. Different techniques are available. Most are relatively invasive. The accurate measurements of blood volume flow are mainly used clinically in vascular and transplant surgery. Currently, the preferred methods in clinical practice use either electromagnetic or ultrasound flowmetry. In both methods the probe has to be placed on the corresponding vessel. This applies especially to electromagnetic probes, where the choice of the size of the probe is crucial and may influence the outcome of the measurement. Both methods are not applicable in the laparoscopic setting, particularly for measurement of volume flow in the portal vein as the vein needs to be dissected. A new noninvasive technique based on magnetic resonance angiography (MRA) became available recently. This method is time consuming, expensive, and not applicable to the intraoperative situation. More recently, ultrasound-based methods for measurement of blood flow velocities via frame domain correlation have been introduced. One such technique, CVI-Q, is available commercially on the P7000 Ultrasound Scanner: Philips Ultrasound Irwin Ca [3]. Although this method is accurate and reliable when compared to invasive ultrasonic flowmetry it could not be used in the present study because of the absence of a laparoscopic transducer probe for this ultrasound scanner. The high correlation of the reliability of volume flow measurements between duplex ultrasound and invasive electromagnetic flowmetry ($r = 0.96$) has been confirmed by several investigators [1–3, 10]. In duplex Doppler flowmetry the mean velocity measurement is multiplied by the vessel area to yield the volume flow, assuming a circular vessel [3]. The outcome of these investigations encouraged us to use Doppler flowmetry in our study. The potential error in estimating exact volume flow is not relevant as the main aim of the study was to estimate the extent of changes in volume flow rather than actual values.

In an experimental study on dogs, Kotzampassi et al. [6] indicated that severe hemodynamic changes in the blood flow to intraperitoneal viscera occur at IPP of 14 mmHg. This included reduction of the intestinal submucosal blood (measured by a laser Doppler) to 50% of the baseline value and elevation of portal and inferior vena cava pressures. A more recent experimental study in the pig reported by Rasmussen et al. [11] documented a significant reduction of the portal venous flow, which has been confirmed in the human by the results of the present investigation. The reported reduction of portal venous flow (66% of baseline volume) at 25 mmHg is accompanied by elevations of the portal/hepatic venous blood pressure and portal/hepatic vascular resistance (360 and 650 of the baseline volume, respectively).

The results of the present study in humans confirm not only the reduction of the portal venous flow but also evidence of a relation between the drop in portal venous flow and the increase of the IPP. These findings suggest the need for further studies on the compensatory mechanisms involved and on the effects of reduced portal flow on liver function during and after laparoscopic surgery, particularly during prolonged laparoscopic operations. The question of whether the reduced portal flow is accompanied by an increased flow in the hepatic artery remains unanswered. The clinical setting of the study did not allow us to prolong the operation time for the sake of additional studies on the hepatic arterial flow in these patients.

There are potential clinical complications that can arise as a consequence of the adverse hemodynamic changes in the splanchnic circulation induced by a sustained elevation of the IPP. The reduced portal flow is likely to result in depression of the hepatic reticular endothelial cell function, which may enhance tumor cell dissemination and increase the likelihood of systemic sepsis. On the other hand, the reduced portal venous flow should enhance the ablative effect of cryosurgery for metastatic disease of the liver by diminishing the heat sink effect of blood perfusing the liver parenchyma.

In view of these observations, a selective setting of IPP during laparoscopic surgery is advisable with low pressure or gasless abdominal wall lift approaches being considered for patients undergoing excisional surgery for cancer. By contrast, the ablative effect of laparoscopic cryotherapy is enhanced in the presence of raised IPP in the 12–14 mmHg range. In any event, during major procedures conducted with a pneumoperitoneum, the IPP should be kept at the lowest level which allows optimal visualization [8]. Also, strategic rest breaks at 2–3-h intervals when the pneumoperitoneum is desufflated are advisable in an attempt to minimize the adverse effects on the splanchnic circulation.

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References

1. Avasthi PS, Greene ER, Voyles WF, Eldridge MW (1984) A comparison of echo-Doppler and electromagnetic renal blood flow measurements. J Ultrasound Med 3: 213–218
2. Dauzat M, Laynargues G (1989) Portal vein blood flow measurements using pulsed Doppler and electromagnetic flowmetry in dogs: a comparative study. Gastroenterology 96: 913–919
3. Forsberg F, Liu J, Russell K, Guthrie S, Goldberg B (1995) Volume

flow estimation using time domain correlation and ultrasonic flowmetry. Ultrasound Med Biol 8: 1037–1045
4. Ivankovich A, Albrecht R, Zahed B, Bonnet R (1974) Cardiovascular collapse during gynecological laparoscopy. IL Med J 1: 58–61
5. Ivankovich A, Miletich D, Albrecht R, Heyman H, Bonnet R (1975) Cardiovascular effects of intraperitoneal insufflation with carbon dioxide and nitrous oxide in the dog. Anesthesiology 42: 281–287
6. Kotzampassi K, Kapanidis N, Kazamias P, Eleftheriadis E (1993) Hemodynamic events in the peritoneal environment during pneumoperitoneum in dogs. Surg Endosc 7: 494–499
7. Kubota K, Kajiura N, Teruya M, Ishihara T, Tsusima H, Ohta S, Nakao K, Arizono S (1993) Alterations in respiratory function and hemodynamics during laparoscopic cholecystectomy under pneumoperitoneum. Surg Endosc 7: 500–504
8. Lam C, Shimi S, Cuschieri A. Thermal characteristics of hepatic cryolesion formed *in vitro* by 3 mm implantable cryoprobe. Cryobiology (in press)
9. Marshall R, Jebson P, Davie I, Scott D (1972) Circulatory effects of carbon dioxide insufflation of the peritoneal cavity for laparoscopy. Br J Anaesth 44: 680–684
10. Moriyasu F, Ban N, Nishida O, Nakamura T, Miyaki T, Uchino H, Kanematsa Y, Koizumi S (1986) Clinical application of an ultrasound duplex system in the quantitative measurement of portal blood flow. J Clin Ultrasound 14: 579–588
11. Rasmussen IB, Berggren U, Arvidsson D, Ljungdahl M, Haglund U (1995) Effects of pneumoperitoneal on splanchnic hemodynamics: an experimental study in pigs. Eur J Surg 161: 819–826
12. Smith I, Benzie R, Gordon N, Kelman G, Swapp G (1971) Cardiovascular effects of peritoneal insufflation of carbon dioxide for laparoscopy. BMJ 3: 410–411
13. Westerband A, Van De Water J, Amzallag M, Lebowitz P, Nwasokwa O, Chardavoyne R, Abou-Taleb A, Wang X, Wise L (1992) Cardiovascular changes during laparoscopic cholecystectomy. Surg Gynaecol Obstet 175: 535–538
14. Winer BJ (1971) Statistical principles in experimental design. McGraw-Hill, New York