Volume 129 Number 4 SURGERY
APRIL 2001

# Surgical research review

# Effect of laparoscopy on intra-abdominal blood flow

**Markus Schäfer, MD,** *and* **Lukas Krähenbühl, MD,** *Zurich, Switzerland*

*From the Department of Visceral and Transplantation Surgery, University of Zurich, Switzerland*

ALMOST EVERY SURGICAL PROCEDURE in the last decade has been performed by using a minimal invasive approach; therefore its technical feasibility is established. Early studies in the 1970s that investigated the physiology of laparoscopy on young healthy women undergoing short gynecologic operations revealed only minor adverse effects. However, patients' characteristics, the complexity of the procedures, and the operating times have changed markedly since general surgery adopted the laparoscopic approach to gastrointestinal disorders. In fact, there is a growing number of clinical and experimental studies that reveal various adverse effects and complications of the pneumoperitoneum. The clinical importance of this data remains unknown, because the vast majority of patients undergoing a laparoscopic operation do not experience any undue complications of a laparoscopic approach either intraoperatively or in the postoperative course. Whereas cardiac, hemodynamic, pulmonary, and renal alterations are transitory effects closely restricted to the intraoperative and perioperative period, metabolic and immunologic effects and the stress response are prolonged during the postoperative course.

Changes in intra-abdominal blood flow (macrocirculation and microcirculation) during laparoscopic operations are predominantly influenced by 3 factors inherent to the method of laparoscopy: (1) intra-abdominal insufflation of carbon dioxide ($CO_2$), (2) increased intra-abdominal pressure (IAP), and (3) the patient's position. Intra-abdominal insufflation of $CO_2$ remains the most widely used technique for establishing a pneumoperitoneum to create a working space; mechanical retracting devices (gasless laparoscopy) or the use of other gases (eg, helium, nitrous oxide, air) have only limited clinical acceptance. Rapid absorption of $CO_2$ during the pneumoperitoneum results in hypercapnia which exerts systemic effects on the hemodynamics and intra-abdominal organ blood flow. Reduced venous return, an elevated diaphragm and increased intrathoracic pressure are secondary effects caused by increased IAP. Finally, extreme change in position (eg, reverse Trendelenburg, lateral position) are needed to achieve adequate operative exposure.

Accepted for publication July 13, 2000.

Reprint requests: Lukas Krähenbühl, MD, Department of Visceral and Transplantation Surgery, University of Zurich, Rämistrasse, CH-8091 Zurich, Switzerland.

Surgery 2001;129:385-9.



0039-6060/2001/$35.00 + 0 **11/60/110224**
doi:10.1067/msy.2001.110224

**Table I.** Alterations of hepatic blood flow during $CO_2$-laparoscopy

| *Study* | *Model* | *Method* | *IAP (mm Hg)* | *Total hepatic flow* | *Portal venous flow* | *Hepatic arterial flow* | *Reversibility* |
|---|---|---|---|---|---|---|---|
| Gutt et al[1] | Rats | Transit-time US | 2 | ND | –22.3% | ND | Yes |
| | | | 4 | | –35.3% | | |
| | | | 6 | | –48.4% | | |
| | | | 12 | | –84.4% | | |
| Jakimowicz et al[2] | Humans | Doppler US | 7 | ND | –37% | ND | Yes |
| | | | 14 | | –53% | | |
| Junghans et al[3] | Pigs | Transit-time US | 8 | ↓ | ↓ | = | Yes |
| | | | 16 | ↓↓ | ↓↓ | | |
| Klopfenstein et al[4] | Pigs | Transit-time US | 15 | = ↑ | = | +49% | Yes |
| Odeberg et al[5] | Humans | Intravascular | 11-13 | = | ND | ND | ND |
| Rasmussen et al[6] | Pigs | ? | 25 | ND | –34% | ND | ND |
| Sala et al[7] | Pigs | IGC | 15 | ND | –76% | ND | ND |
| Schäfer et al[8] | Rats | Microspheres | 4/10 | –37.2% | –46.2% | = | Yes |
| Schilling et al[9] | Humans | Doppler US | 10 | = | ND | ND | Yes |
| | | | 15 | –39% | | | |
| Takagi et al[10] | Humans | Doppler US | > 10 | ND | ↓ | ND | ND |
| Tunon et al[11] | Pigs | IGC | 14 | ↓↓ | ND | ND | ND |
| Windberger et al[12] | Pigs | ? | 7 | = | = | = | Yes |
| | | | 14 | ↓ | –17.7% | = | |

*IAP,* Intra-abdominal pressure; *US,* ultrasonography; *IGC,* indocyanine green clearance; *ND,* not defined.

This review is focused on alterations in intra-abdominal organ blood flow during $CO_2$-laparoscopy with special regard to the hepatic, splanchnic, and renal circulations.

## ALTERATIONS OF HEPATIC BLOOD FLOW

Impairment of the hepatic circulation, in particular portal blood flow, induced by intra-abdominal insufflation of different gases (eg, $CO_2$, helium, and argon) or fluid has been documented in various experimental and clinical studies. Measurements of blood flow were performed either by using direct methods (Doppler and transit-time ultrasonography or intravascular catheters) or indirect methodology (indocyanine green clearance, thermodilution and γ–labeled microsphere technique). Table I summarizes data from 4 human and 8 animal studies on portal, hepatic arterial, and total hepatic blood flow during $CO_2$-pneumoperitoneum.[1-12] Although methodological restrictions must always be kept in mind, intra-abdominal insufflation of $CO_2$ causes a marked and rapid decrease (35% to 84%) in portal blood flow. This reduction in portal blood flow correlates in most studies with the degree of IAP. Reduction of portal blood flow may be caused by either mechanical compression of the thin-walled portal vein or by hypercapnia-induced vasoconstriction, whereas hepatic arterial flow (thick-walled vessel with arterial pressure) appears to be less compromised by IAP between 10 and 15 mm Hg. In fact, impaired portal blood flow even occurred when hypercapnia was avoided by controlled hyperventilation or when increased IAP was induced by helium, argon, and liquid insufflation. In contrast, alterations in the local and systemic humoral response during laparoscopy, such as release of endothelins, vasopressin, and catecholamines are only partially elucidated. Furthermore, changes at the cellular level (eg, hepatocytes, endothelial, and Kupffer cells) remain unidentified.

The large range of impairment in portal blood flow may be explained by the use of different experimental models, modes of fluid maintenance and ventilation, and also the patient's position on the operating table.[3,4] In particular, hypovolemia and hypercapnia are important cofactors that further decrease portal blood flow, even if IAP is not increased. In general, portal blood flow rapidly normalizes within a few minutes of desufflation of the peritoneal cavity, and there is no evidence for a sustained impairment in hepatic circulation postoperatively.

In contrast, the extent of alteration in hepatic arterial blood flow remains controversial. The majority of studies describe few if any changes in hepatic arterial flow during laparoscopy, and only Klopfenstein et al[4] found a substantial (49%) increase in hepatic arterial flow. Therefore, changes of total hepatic blood flow seem to be dependent on alterations in portal blood flow dur-

**Table II.** Alterations of splanchnic blood flow during $CO_2$-laparoscopy

| *Study* | *Model* | *Method* | *IAP (mm Hg)* | *Mesenteric arterial flow* | *Gastric (mucosal) pH* | *Hollow/ solid organ blood flow* | *Reversibility* |
|---|---|---|---|---|---|---|---|
| Blobner et al[16] | Pigs | Iv catheter | 4-12 | 12%-24% ↑ | ND | ND | ND |
| | | | > 12 | ↓ | | | |
| Knolmayer et al[17] | Pigs | Tonometry | 8-18 | ND | ↓ | ND | ND |
| Schäfer et al[8] | Rats | Microspheres | 4-10 | ND | ND | –64% | Yes |
| Schilling et al[9] | Humans | Doppler US | 10 | ND | ND | –40% | Yes |
| | | | 15 | | | –54% | |
| Windberger et al[12] | Pigs | Tonometry | 7 | ND | = | ND | Yes |
| | | | 14 | | ↓ | | |

*IAP,* Intra-abdominal pressure; *Iv,* intravascular; *ND,* not defined; *US,* ultrasonography.

**Table III.** Alterations of renal blood flow, GFR, and urinary output during $CO_2$-laparoscopy

| *Study* | *Model* | *Method* | *IAP (mm Hg)* | *Renal blood flow* | *GFR* | *Urinary output* | *Reversibility* |
|---|---|---|---|---|---|---|---|
| Cisek et al[19] | Pigs | Transit-time US, insulin clearance, Foley catheter | 20 | –12% | –63% | –80% | Yes |
| Hashikura et al[20] | Pigs | ? | 6-24 | ↓ | ND | ND | ND |
| Junghans et al[3] | Pigs | Transit-time US | 8-16 | ↓ | ND | ND | Yes |
| Koivusalo et al[18] | Humans | Clearance, Foley catheter | 12 | ND | ND | ↓ | ND |
| London et al[22] | Pigs | Transit-time-US, Foley catheter | 15 | ↓ | ND | ↓ | Yes |
| Schäfer et al[8] | Rats | Microspheres | 4-10 | –40.6% | ND | ND | Yes |
| Shuto et al[21] | Pigs | Foley catheter | 8-20 | ↓ | ND | ↓ | ND |

*GFR,* Glomerular filtration rate; *IAP,* intra-abdominal pressure; *US,* ultrasonography; *ND,* not defined.

ing $CO_2$-laparoscopy without a compensatory increase in hepatic arterial blood flow. However, total hepatic blood flow, in particular portal blood flow, can be restored by the use of various pharmacological agents, such as nifedipine, dopamine, and phosphodiesterase III inhibitors during the pneumoperitoneum.[13,14]

The clinical importance of reduction in hepatic (portal) blood flow is still under debate. The majority of patients undergoing various laparoscopic procedures do not exhibit any increased intraoperative or postoperative morbidity. Nevertheless, these decreases in hepatic blood flow may reduce hepatic protein synthesis (eg, fibrinogen and albumin) and may alter hepatic clearance of pharmacological agents, portal bacteremia, and endotoxins as well as tumor cell clearance.[15] Elderly patients with generalized atherosclerosis and pre-existing liver disease may be at increased risk of hepatic ischemia and its consequences. In these patients, long operating times, prolonged IAP, and extreme reverse Trendelenburg position should be avoided. Pharmacological prevention of impaired hepatic circulation during laparoscopy may need further evaluation.

## ALTERATIONS OF SPLANCHNIC AND RENAL BLOOD FLOW

As shown in Table II, intestinal circulation of hollow viscus organs (stomach and small and large bowel) and of solid organs (liver, spleen, pancreas, and kidneys) reveals a decrease in blood flow during laparoscopy with increased IAP similar to that of hepatic blood flow.[8,9,12,16,17] However, the extent of flow reduction and the IAP needed to achieve these negative circulatory effects range broadly. Although some authors using indirect methods, predominantly intestinal tonometry, have only described an overall reduction of pH values and were unable to quantify flow impairment exactly, Schilling et al[9] have reported a decrease in blood flow of 40% to 54% in the stomach, 32% in the jejunum, and 44% in the colon during laparoscopy in human beings. In our study[8] in rats, we found a different reduction in blood flow for hollow organs and solid organs, where the microcirculation in the solid organs was more suppressed. Furthermore, the position on the operating table, ventilation modes, and volemic state are important cofactors influencing splanchnic circulation.[3,4] Despite methodological limitations, there is evidence that decreased cardiac output and increased vascular resistance are caused by increased IAP and hypercapnia. When using mechanical retractors to lift the abdominal wall (gasless laparoscopy), no impairment of intestinal blood flow was detected.[18] Whether the impaired microcirculation of the small bowel during pneumoperitoneum causes a clinically relevant damage to the mucosal barrier with a subsequent increase in bacterial and endotoxin influx has not yet been elucidated.

Although the kidneys are extraperitoneal, there is strong evidence that the increased IAP during laparoscopy causes a decrease in both renal blood flow and urinary output (Table III). Various animal models have shown that IAP may correlate with the decrease in renal blood flow, which ranges from 12% to 40%.[3,8,17,19-22] Reduction in urinary output normalizes within a few postoperative hours as hypercapnia resolves. Several factors lead to impaired urinary output. Not only are increased IAP and hypercapnia involved, but also increased serum levels of vasopressin and relative hypovolemia. As shown for splanchnic circulation, renal blood flow is preserved by gasless laparoscopy and normocapnia. In addition, according to some animal studies, intravascular volume expansion and warm insufflation of $CO_2$ may be protective. Because laparoscopic living donor nephrectomy for kidney transplantation is gaining clinical importance as a result of organ shortage, alterations in renal blood flow and microcirculation and their impact on subsequent function of the transplanted kidneys need further evaluation.

## CONCLUSION

The benefit offered by laparoscopy is the minimal access into the peritoneal cavity, the main impact of which involves the postoperative recovery. The surgical procedure itself remains unchanged. However, the technique of laparoscopic surgery necessitates methodological requirements that may be associated with adverse effects on the patient's intraoperative physiology. Numerous studies using various animal and human models and sophisticated measurement techniques have shown a variety of adverse effects caused by increased IAP and hypercapnia. In addition, patient position, volemic state, ventilation mode, and individual comorbidities are relevant cofactors influencing the laparoscopy-induced alterations. intra-abdominal blood flow to hollow and solid organs is reduced by 10% to 80% but rapidly normalizes after desufflation of the abdominal cavity. For the majority of patients undergoing laparoscopic procedures, this reduction in blood flow has no clinical impact, although cardiac arrhythmias and reduced urinary output are frequently observed. However, further studies are needed to reveal whether reduced microcirculation in diseased organs (eg, liver cirrhosis, small bowel ileus, kidney transplantation) and prolonged operating times may have potential adverse effects for the laparoscopic approach.

Whether the amount of blood flow reduction is strictly correlated to the IAP remains controversial. However, the IAP should probably be kept between 8 and 12 mm Hg to minimize alterations in blood flow. Controlled hyperventilation should be used to correct hypercapnia and its systemic adverse effects. The clinical impact of pharmacological prevention and correction of volemic state to restore organ blood flow remains to be defined.

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