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Hemodynamic consequences of high- and low-pressure capnoperitoneum during laparoscopic cholecystectomy

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Background: Peritoneal insufflation to 15 mmHg diminishes venous return and reduces cardiac output. Such changes may be dangerous in patients with a poor cardiac reserve. The aim of this study was to investigate the hemodynamic effects of high (15 mmHg) and low (7 mmHg) intraabdominal pressure during laparoscopic cholestectomy (LC)
Methods: Twenty patients were randomized to either high- or low-pressure capnoperitoneum. Anesthesia was standardized, and the end-tidal CO_2 was maintained at 4.5 kPa. Arterial blood pressure was measured invasively. Heart rate, stroke volume, and cardiac output were measured by transesophageal doppler.
Results: There were 10 patients in each group. In the high-pressure group, heart rate (HR) and mean arterial blood pressure (MABP) increased during insufflation. Stroke volume (SV) and cardiac output were depressed by a maximum of 26% and 28% (SV $0.1 > p > 0.05$, cardiac output $p > 0.1$). In the low-pressure group, insufflation produced a rise in MABP and a peak rise in both stroke volume and cardiac output of 10% and 28%, respectively ($p < 0.05$).
Conclusions: Low-pressure pneumoperitoneum is feasible for LC and minimizes the adverse hemodynamic effects of peritoneal insufflation.

Key words: Laparoscopic cholecystectomy — Hemodynamics — Intraabdominal pressure

The recent popularity of laparoscopic general surgery has resulted in a resurgence of interest in the physiologic effects of peritoneal insufflation. The hemodynamic effects of insufflation were originally investigated in gynecologic patients [8–11, 14], and included elevation of heart rate, arterial blood pressure, central venous pressure and peripheral vascular resistance, and depression of stroke volume and cardiac output. Such changes were generally well tolerated and were more pronounced in patients with a higher intraabdominal pressure. In general surgery, laparoscopy is performed increasingly on older and often more unfit patients, and the operation may take considerably longer. Cardiovascular impairment as a result of peritoneal insufflation may be hazardous in these circumstances.

In an attempt to minimize the hemodynamic effects of insufflation in humans, we have therefore developed a technique for laparoscopic cholecystectomy at low intraabdominal pressure. In this study we evaluated the technique and compared the hemodynamic effects of insufflation with CO_2 at low pressure (7 mmHg) and standard pressure (15 mmHg).

Patients and methods

Local ethical committee approval was obtained for the study. Patients admitted for elective laparoscopic cholecystectomy under the care of one consultant surgeon (M.J.M.) were invited to take part in the study, and fully informed consent was obtained. Patients were ASA grade I or II. Patients with higher ASA grades were excluded from the study. The details of the patients are given in Table 1.

Randomization to high- or low-pressure pneumoperitoneum was performed immediately before the operation, and the surgeon was informed of the randomization at the time of skin incision. A standardized anesthetic technique was used for all patients. Anesthesia was induced and maintained with infusions of propofol and alfentanyl. The minute ventilation was adjusted to maintain the end tidal CO_2 at 4.5 kPa, and a radial artery catheter was inserted to measure arterial blood pressure.

An esophageal doppler probe (ODM; Abbott Laboratories Ltd, Queenborough, Kent, England) was placed in the intrathoracic esophagus just above the hiatus at the point of maximal signal. In all patients, primary closed cannulation was performed after peritoneal insufflation with CO_2 to a pressure of 15 mmHg. After placement of all four laparoscopic cannulae, the intraabdominal pressure was either maintained at 15 mmHg or reduced to 7 mmHg by adjustment of the insufflator.

In patients randomized to low-pressure insufflation, a laparoscopic liver retractor was inserted via the lateral right cannula and used to elevate the liver edge. This maneuver assists in exposure of the gallbladder and allows for either antegrade or retrograde dissection [12]. Patients randomized to receive high-pressure insufflation underwent cholecystectomy by

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Table 1. Details of the patients

	Low pressure (7 mmHg) ($n = 10$)	High pressure (15 mmHg) ($n = 10$)
Age mean (range)	48 (19–72)	56 (27–71)
Sex M : F	3 : 7	4 : 6
BMI (kg/m^2) mean (range)	25.4 (18.1–32.2)	27 (20.1–30.9)
Previous cardiac disease	1 hypertensive	1 hypertensive 2 previous CABG

CABG, coronary artery bypass graft; BMI, body mass index.

the standard American technique [21] employing gallbladder fundal retraction. Insufflation was performed with all patients in the supine position. In eight patients (four in each group), a head up position of 10 to 15% was used during dissection of the gallbladder to aid exposure.

Measurements of heart rate (HR), mean arterial blood pressure (MABP), stroke volume (SV), cardiac output, and intraabdominal pressure (IAP) were made when the patient had been stabilized after induction of anesthesia, but before commencement of surgery, immediately after peritoneal insufflation, and at 5-min intervals until the completion of skin closure.

Heart rate, stroke volume, and cardiac output were measured by the esophageal doppler probe. Arterial blood pressure was measured invasively using a transducer (Ohmeda, Hatfield, England). End-tidal CO_2 was measured directly from the expired anesthetic gas (Datascope, Accucap), and the intraabdominal pressure was assessed by the automatic insufflator (Stryker High Flow Insufflator, Stryker Ltd, Reading, UK).

In order to include complete data from all patients, only the first 35 min of pneumoperitoneum were analyzed. Changes in stroke volume and cardiac output were analyzed as a percentage of each individual's baseline value, which was the mean of two preinsufflation values. The HR and MABP are presented as actual values. Changes within each group were assessed with analysis of variance (ANOVA). Comparison of the two groups was performed by comparing the area under the curve for the duration of the pneumoperitoneum with the baseline at 0 units. Mean values for each group were compared by unpaired Student's *t*-test.

Results

Three patients were withdrawn from the study. Two in the low-pressure group had marked gallbladder adhesions. Dissection of the adhesions was bloody and required considerable suction and irrigation, which precluded the maintenance of low-pressure pneumoperitoneum. In both cases the pressure was increased to 15 mmHg, and the operation was completed uneventfully. One patient in the high-pressure group required conversion to open cholecystectomy for uncontrolled bleeding from the cystic artery.

The remaining 10 patients in each group were well matched for age, sex ratio, and body mass index. A history of significant cardiovascular disease was present in four patients. One patient in the low-pressure insufflation group had borderline untreated hypertension. One patient in the high-pressure group was hypertensive and controlled with enalapril, and two further patients in the same group had previously undergone coronary artery bypass surgery, respectively, 5 and 10 years earlier. Of these, one patient was taking nifedipine at the time of the study, but was asymptomatic.

The mean duration of operation (total anesthetic time) was 103.5 (range, 50–180) min for the low-pressure group compared with 117.5 (range, 60–180) min for the high-pressure group (p = NS). There was one postoperative complication in each group. In the low-pressure group, one patient was readmitted with a subhepatic abscess 7 days after cholecystectomy. At the time of the operation, several stones had been spilled. All the stones were thought to have been retrieved at the original operation, but subsequent laparotomy revealed a number of gallstones within the abscess cavity. The patient recovered uneventfully after his laparotomy. One patient in the high-pressure group developed a minor wound infection at the umbilical port site, which was treated successfully with antibiotics. The intraabdominal pressure and cardiovascular changes are shown in Figs. 1 to 5. The comparative results from the two groups are shown in Table 2.

Intraabdominal pressure (Fig. 1)

The actual intraabdominal pressure in the two study groups is shown in Fig. 1. After initial cannulation at 15 mmHg, the pressure in both groups settled at a level slightly below the selected preset pressure, as a result of gas leakage and the use of suction.

Heart rate (Fig. 2)

Peritoneal insufflation was associated with a moderate increase in heart rate, which reached statistical significance for the high-pressure group ($p < 0.05$). The increased heart rate returned to normal after desufflation. There was no statistical difference between the two groups.

Mean arterial blood pressure (Fig. 3)

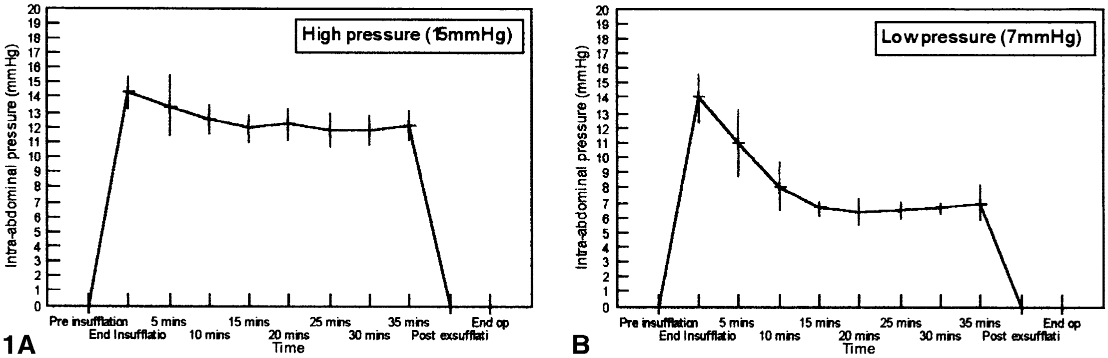
Mean arterial pressure rose significantly in both groups on peritoneal insufflation ($p < 0.01$ high, $p < 0.05$ low). Although this was reduced to some extent during surgery, the post exsufflation blood pressure remained higher than the preoperative (postinduction) value in both groups ($p < 0.05$ high, $p < 0.01$ low; Student's *t*-test). There was no significant difference between the two groups.

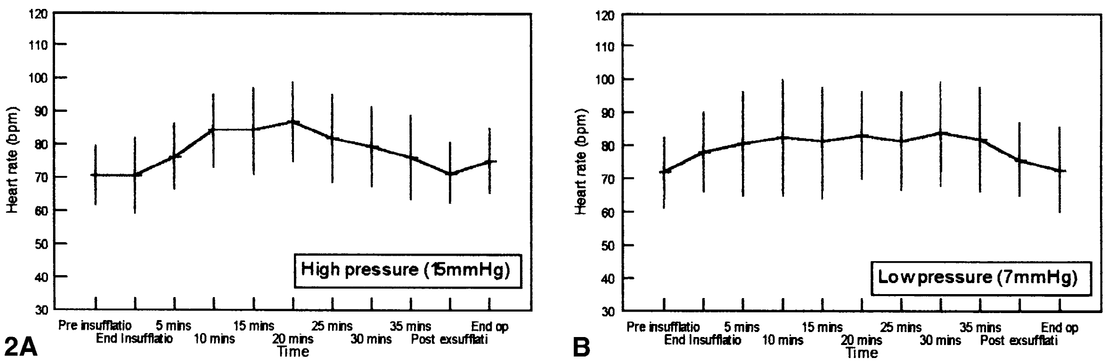
Stroke volume (Fig. 4)

Initial insufflation produced a similar reduction in stroke volume in both groups (21% low, 24% high). After stabilization at the randomized pressure, the stroke volume in the high-pressure group remained approximately 10% lower than the preoperative baseline, whereas in the low-pressure group the stroke volume was increased by up to 10% compared with the baseline value. The area under the stroke volume curve was significantly greater in the low-pressure group ($p < 0.04$) than in the high-pressure group.

Cardiac output (Fig. 5)

Cardiac output was reduced initially in both groups by peritoneal insufflation. In the high-pressure group cardiac out-





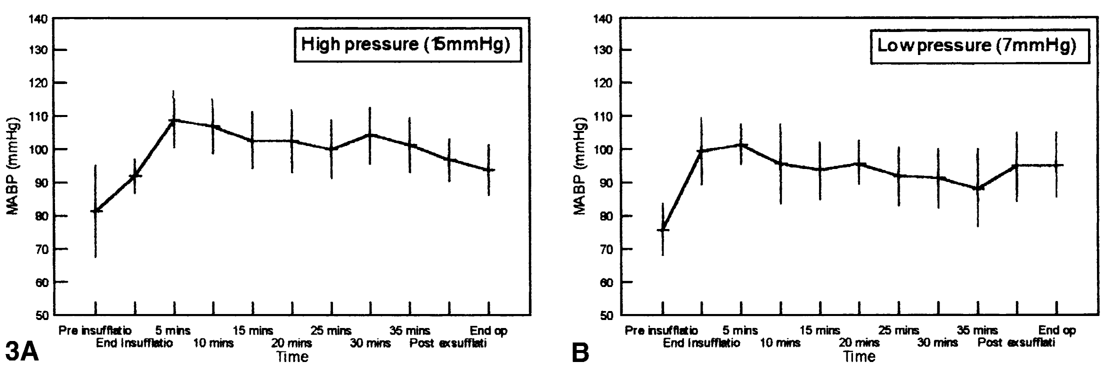


Fig. 1. A, B Intraabdominal pressure. Graphs show the changes in intraabdominal pressure for both groups during the study. The line refers to the mean intraabdominal pressure (mmHg), and the error bars represent the upper and lower 95% confidence intervals.

Fig. 2. A, B Heart rate. Graphs show the changes in heart rate in both groups. The line refers to the mean rate (beats per minute), and the error bars represent the upper and lower 95% confidence intervals.

Fig. 3. A, B Mean arterial blood pressure. Graphs show the changes in mean arterial blood pressure (MABP) in both groups. The line refers to the mean blood pressure (mmHg), and the error bars represent the upper and lower 95% confidence intervals.

put returned toward the baseline value during surgery. At low intraabdominal pressure cardiac output increased to a maximum of 20% above the baseline value and was maintained at this level until release of the pneumoperitoneum. The area under the cardiac output curve was significantly greater in the low-pressure group ($p < 0.04$) than in the high-pressure group.

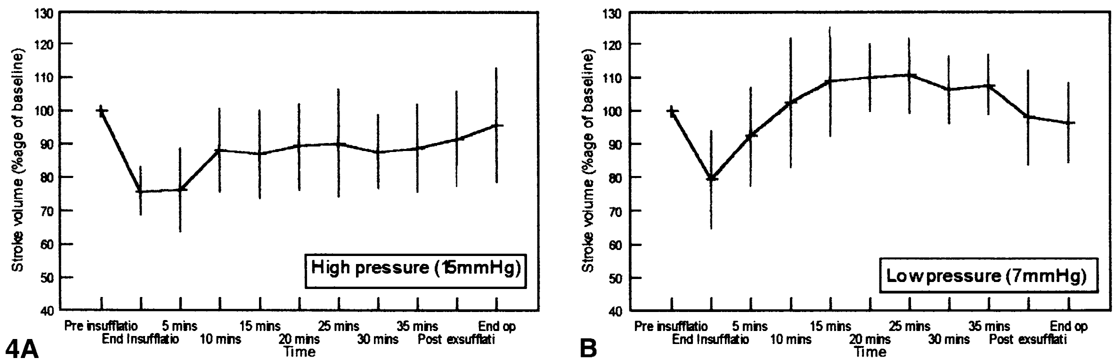
Table position

The effect of reverse Trendelenberg tilt on stroke volume and cardiac output is shown in Table 3. Although some tilt was used in four patients in each group, there was no overall change in either stroke volume or cardiac output. Transient changes in hemodynamic parameters were observed around the time of table tilt, but were no greater than the fluctuations seen at other times during the operation. The degree and direction of change varied widely in both groups.

Discussion

The deleterious effects of increased intraabdominal pressure on stroke volume, cardiac output, and other hemodynamic variables have been well established in human subjects and animal models. The degree to which cardiac output is reduced depends on a number of variables including volemic status [2] insufflating gas [4, 11], patient position [20], and intraabdominal pressure [2, 5, 7, 8, 16].

In this study the insufflating gas was the same, and the patients in both groups had identical preoperative care.



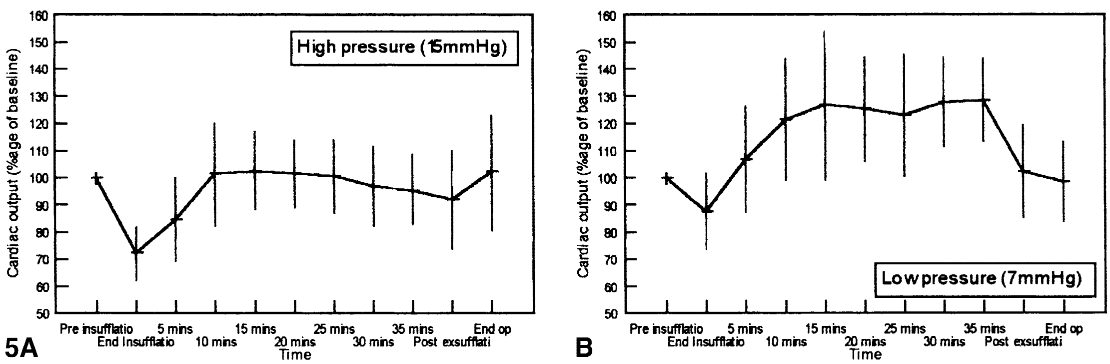


Fig. 4. A, B Stroke volume. Graphs show the changes in stroke volume with respect to the baseline (percentage) in both groups. The line refers to the mean value, and the error bars represent the upper and lower 95% confidence intervals.

Fig. 5. A, B Cardiac output. Graphs show the changes in cardiac output with respect to the baseline (percentage) in both groups. The line refers to the mean value, and the error bars represent the upper and lower 95% confidence intervals.

Table 2. Hemodynamic effects of capnoperitoneum

	Low pressure (7 mmHg) (n = 10)	High pressure (15 mmHg) (n = 10)	p value[a]
Heart rate	2834 (2460–3208)	2862 (2366–3358)	$p = 0.93$
MABP	3611 (3355–3867)	3318 (3112–3524)	$p = 0.09$
Stroke volume	3004 (2610–3398)	3628 (3216–4040)	$p = 0.04$
Cardiac output	3347 (2899–3795)	4186 (3600–4772)	$p = 0.04$

[a] unpaired Student's t-test.
MABP, mean arterial blood pressure.
Values are arbitrary units of area under the curve (baseline = 0) for each group during insufflation. All values are means with 95% confidence intervals in parentheses.

Table 3. Effect of reverse Trendelenberg tilt

	Stroke volume median (range)	Cardiac output median (range)
High pressure (n = 4)	97% (79–110%)	109% (83–113%)
Low pressure (n = 4)	111% (99–118%)	104% (86–119%)
	NS	NS

NS, not significant (Mann Witney U-test).
Values shown are measurements of stroke volume and cardiac output taken after the application of head-up tilt as a percentage of the measurement preceeding tilt (range in parentheses).

Therefore, we would not expect any difference in volemic status between the two. The position of the patients was predominantly supine, although some reverse Trendelenberg tilt was applied in eight patients after insufflation. The overall effect of tilt was negligible, although cardiac output and stroke volume appeared in some individual patients either to increase or to decrease transiently. Other authors have observed a measurable reduction in cardiac index after head-up tilt in human subjects both before [6] and after insufflation [3]. Although these observations are not borne out by our own data, we did not apply the reverse Trendelenberg position routinely and were encouraged that tilt was unnecessary for exposure in most patients, regardless of insufflation pressure.

The depressive effect on cardiac output of 15 mm Hg intraabdominal pressure has been observed during surgical laparoscopy [6, 13, 19]. One previous study has compared insufflation at 15 mm Hg with a low pressure of 7.5 mmHg during laparoscopic cholecystectomy. The authors showed that both pressures caused transient reduction in cardiac and stroke index, which recovered more quickly after low-pressure insufflation. Our finding that 7 mmHg intraabdominal pressure increases stroke volume and cardiac output has not been previously demonstrated in humans. A similar finding has been observed in dogs, in which stepwise increases in intraabdominal pressure resulted in progressive depression of stroke volume, except when low-pressure (5 mmHg) insufflation was used [2, 5, 7, 16]. Low-pressure insufflation enhanced stroke volume.

The physiologic basis for these findings was studied in detail by Kashtan et al. [7]. These authors demonstrated that inferior vena caval (IVC) flow, and by extrapolation stroke volume, is governed by two opposing influences in the presence of raised intraabdominal pressure. The mean systemic pressure is the driving pressure that empties the capacitance veins and increases caval flow. Venous resistance, by contrast, inhibits venous flow and hence return. Raised intraabdominal pressure increases both mean systemic pressure and venous resistance. In dogs, venous resistance is insignificant, below 5–7 mmHg, and at such low pressure there is a net increase in venous flow. Above this pressure, venous resistance becomes dominant and caval flow decreases. Contrast studies of the IVC during insufflation [17] have demonstrated that in humans the anatomic site of maximum resistance is just below the diaphragm, at which point the IVC collapses with raised intraabdominal pressure.

In common with other studies of laparoscopic cholecystectomy (LC) in humans using invasive [6] and noninvasive monitoring [18], some compensation in cardiac output did occur after initial insufflation in the high-pressure group in our study. However, stroke volume remained below the preinsufflation baseline, which, in the presence of increased arterial blood pressure, suggests that the peripheral vascular resistance is elevated by peritoneal insufflation. This has previously been noted by many authors [1, 2, 6, 14, 19], and concern has been raised that such an increase in afterload could be poorly tolerated in some high-risk patients [19].

At 7 mmHg intraabdominal pressure, stroke volume and cardiac output were elevated compared with the postinduction baseline values. As anesthesia itself may be associated with a significant drop in cardiac output [1, 6], it is not clear if the stroke volume and cardiac output would have been higher than the preanesthetic values. Wallace et al [18] did not observe an increase above the baseline, which was also established after the induction of anesthesia. They insufflated only to 7.5 mmHg after open primary cannulation, whereas all our patients were cannulated at 15 mmHg before the lower pressure was established in those randomized to 7 mmHg. It is possible that the increase in stroke volume above the baseline represents a rebound phenomenon, although it was maintained throughout the insufflation period.

An alternative theory is that the different methods of retraction affect stroke volume. The liver retractor used in the low-pressure group elevates the liver edge, potentially relieving pressure on the inferior vena cava. In the high–pressure group, forcible gallbladder retraction was used, which pushes the gallbladder and undersurface of the liver cephalad. This maneuver could apply more pressure on the inferior vena cava and result in a reduction of caval flow and hence stroke volume. Another advantage of the retractor was that we did not experience difficulty with access in the low-pressure group.

Excess CO_2 results in an increase in sympathoadrenal activity, and absorption of CO_2 from the peritoneum probably accounts for the elevation in heart rate and mean arterial pressure observed in both groups. Excessive hypercarbia is detrimental because cardiac work is increased and myocardial oxygen requirement outstrips supply, resulting in endocardial ischaemia [15]. End-tidal CO_2 was therefore controlled by adjustment of the minute volume.

From the anesthetist's point of view, although the MAP and HR appear well maintained in both groups, doppler measurement clearly shows that a high insufflation pressure has deleterious effects on both stroke volume and cardiac output in physiologically normal patients. These effects could be compounded in less fit patients, and indeed ordinary noninvasive HR, ECG, and blood pressure measurements would not necessarily be capable of detecting any adverse effect on cardiovascular physiology until too late. A case could therefore be made for low-pressure insufflation in all unfit patients, with more invasive monitoring in particularly high-risk individuals.

Conclusions

The use of an intraabdominal pressure as low as 7 mmHg alleviates many of the adverse hemodynamic effects of insufflation and may be suited particularly to patients with poor cardiovascular reserve. The results from this study show that it is possible to complete the procedure at this pressure in most patients.

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