Surg Endosc (2001) 15: 477–483
DOI: 10.1007/s004640000343

Surgical Endoscopy
Ultrasound and
Interventional Techniques

Hemodynamic and pulmonary changes during open, carbon dioxide pneumoperitoneum, and abdominal wall-lifting cholecystectomy

A prospective, randomized study

G. Galizia, G. Prizio, E. Lieto, P. Castellano, L. Pelosio, V. Imperatore, A. Ferrara, C. Pignatelli

Department of Surgical Sciences, General and Hepato-Biliary Surgery Unit, Second University of Naples School of Medicine, c/o II Policlinico, Ed. 17, Via S. Pansini, 5, 80131 Naples, Italy

Received: 18 May 2000/Accepted in final form: 9 August 2000/Online publication: 21 December 2000

Abstract
Background: Carbon dioxide (CO_2) pneumoperitoneum effects are still controversial. The aim of this study was to investigate cardiopulmonary changes in patients subjected to different surgical procedures for cholecystectomy.
Methods: In this study, 15 patients were assigned randomly to three groups according to the surgical procedure to be used: open cholecystectomy (OC), CO_2 pneumoperitoneum cholecystectomy (PP), and laparoscopic gasless cholecystectomy (abdominal wall lifting [AWL]), respectively. A pulmonary artery catheter was used for hemodynamic monitoring in all patients. A subcutaneous multiplanar device (Laparo Tenser) was used for abdominal wall lifting. To avoid misinterpretation of results, conventional anesthesia was performed with all parameters, and the position of the patients held fixed thoroughout surgery. The following parameters were analyzed: mean arterial pressure (MAP), heart rate (HR), cardiac output (CO), cardiac index (CI), stroke volume index (SVI), central venous pressure (CVP), systemic vascular resistances index (SVRI), mean pulmonary arterial pressure (MPAP), pulmonary capillary wedge pressure (PCWP), pulmonary vascular resistances index (PVRI), peak inspiratory pressure (PIP), end-tidal CO_2 pressure $(ETCO)_2$, CO_2 arterial pressure ($PaCO_2$), and arterial pH.
Results: All the operations were completed successfully. The Laparo Tenser allowed good exposition of the surgical field. A slight impairment of the cardiopulmonary functions, with reduction of SVRI, MAP, and CI and elevation of pulmonary pressures and vascular resistance, followed induction of anesthesia. However, these effects tended to normalize in the OC and AWL groups over time. In contrast, CO_2 insufflation produced a complex hemodynamic and pulmonary syndrome resulting in increased right- and left side filling pressures, significant cardiac index reduction, derangement of the respiratory mechanics, and respiratory acidosis. All of these effects normalized after desufflation.
Conclusions: Cardiopulmonary adverse effects of general anesthesia were significant but transitory and normalized during surgery. Carbon dioxide pneumoperitoneum caused a significant impairment in cardiopulmonary functions. In high-risk patients, gasless laparoscopy may be preferred for reliability and absence of cardiopulmonary alterations.

Key words: Abdominal wall lifting — Cardiopulmonary functions — Laparoscopic surgery — Laparo Tenser — Pneumoperitoneum

Laparoscopic abdominal surgery has been used increasingly over the past 10 years, thus becoming the preferred technique for treatment of several intra-abdominal diseases [9]. Many studies have demonstrated that both intra- and postoperative complication rates and long-term results of laparoscopy are similar to those of open surgery [6,18]. Moreover, less postoperative pain, shorter hospital stay, and better long-term cosmetic results usually can be predicted after laparoscopic surgery [14]. Laparoscopic methods depend essentially on the establishment of an intraperitoneal space [4]. A pneumoperitoneum using carbon dioxide (CO_2) therefore is routinely induced to give the region of interest a good exposure [3].

Although CO_2 pneumoperitoneum (PP) has been proved safe and effective, a number of clinical and experimental studies have demonstrated that PP may be detrimental to cardiopulmonary performance [13, 20]. Other complications include hypercapnia and acidemia [5], gas embolism [18], mesenteric ischemia [7], decreased hepatic and renal blood flow [11,12], increased intracranial pressure [10], and enhancement of intra-abdominal tumor spread and implan-

Correspondence to: G. Galizia

tation [8]. To obviate the consequences of PP, alternative methods, such as abdominal wall lifting (AWL), have been proposed recently [2, 4,15]. Basically, AWL techniques provide abdominal exposure with a low-pressure pneumoperitoneum or even without pneumoperitoneum (so-called gasless laparoscopy [4]), and probably with no or insignificant effects on cardiorespiratory functions [13,19]. However, the hemodynamic and pulmonary alterations associated with gasless laparoscopy have not been investigated completely, and at this writing, only a few studies have compared PP with AWL in humans [11].

This randomized, controlled trial was designed to investigate changes in cardiac and pulmonary functions in patients undergoing surgical cholecystectomy or laparoscopic cholecystectomy, with or without pneumoperitoneum, in order to establish whether gasless laparoscopy, which is thought to be associated with less hemodynamic and pulmonary changes, may constitute an option in patients who are not ideal candidates for pneumoperitoneum, such as those with cardiopulmonary problems.

Materials and methods

Patients

From October 1999 to December 1999, 33 consecutive patients with symptomatic gallstones eligible for cholecystectomy were enrolled initially in this study. The eligibility criteria required an age 45 years or younger, regular body weight and height, no previous abdominal surgery, no gallstone-related complications, absence of cardiovascular or respiratory dysfunction, American Society of Anesthesiology (ASA) class I surgical risk, and informed consent. Because the study was conceived as a three-arm trial with five patients in each arm, it was stopped in December 1999 after 15 patients had been enrolled. The remaining 18 patients were excluded for various reasons. Only two patients refused randomization.

In all patients, a pulmonary artery (Swan-Ganz) catheter was inserted from the left cubital vein or internal jugular vein on the day before surgery. Although hemodynamic monitoring could be assessed by using many noninvasive techniques such as transoesophageal echocardiography or the bioimpedance method [11, 17], pulmonary artery catheterism undoubtedly is the best technique for obtaining a large set of data [10]. However, because of certain complications related to its use, the Swan-Ganz catheter has been used only in critical patients or for animal studies [3, 20]. After approval by the Ethics Committee of the Second University of Naples, Department of Surgical Sciences, we decided to use such an invasive system to obtain a thorough hemodynamic monitoring.

Each patient after being carefully informed and gave undersigned consent. A sealed envelope, opened in the operating room, randomized five patients to an open cholecystectomy (OC group), five patients to a CO_2 pneumoperitoneum laparoscopic cholecystectomy (PP group), and five patients to a gasless laparoscopic cholecystectomy (AWL group), respectively.

Abdominal wall lifting

A new multiplanar lifting device working under isopneumic conditions, the Laparo Tenser, L+T Lucini, Paderno Dugnano (MI), Italy, was used for gasless laparoscopy. The Laparo Tenser, designed by an Italian engineer, Dr. Lucini, consists of an abdominal wall retractor with two convex-shaped needles attached to a mechanical lifting arm. The needles are inserted subcutaneously to avoid muscle lacerations and peritoneum compression. The final effect is a planar lifting that is more advantageous than the linear lifting obtained with the use of other devices [4, 15, 19].

Anesthesia and operation

Anesthesia was standardized as follows: all the patients were premedicated with midazolam (5mg) and atropine hydrochloride (0.01 mg/kg) administered intramuscularly (IM). General anesthesia was induced with a bolus of propofol (2 mg/kg) and fentanyl (5 μg/kg). Muscular relaxation was obtained with cisatracurium besylate (0.15 mg/kg). Anesthesia was maintained with continuous infusion of propofol (6 mg/kg/h) and supplemental doses of fentanyl (100 μg) and cisatracurium (0.03 mg/kg) every 30 min. Mechanical ventilation was performed using fraction of inspired oxygen (FiO_2) 40% in air at a rate of 12 breaths/min and a tidal volume of 8 ml/kg. Fluid administration was restricted, and Ringer's lactate was given intravenously (IV) at 5 ml/kg/h. During all the procedures, the patients were maintained in the supine position to avoid the well-known cardiopulmonary effects of the reverse Trendelenburg position [5]. To avoid confusing results, no hemodynamic or respiratory adjustments were performed.

Open cholecystectomy was performed through a right subcostal incision. Patients in the PP group had a 12-mmHg pneumoperitoneum by a Veress needle, which was maintained during the operation by an automatic gas insufflator. Two 10-mm trocars (paraumbilical and right upper quadrant) and two 5-mm trocars (epigastrium and left upper quadrant) were inserted. In the AWL group, after placement of subcutaneous needles, a 10-mm optical trocar was inserted through a small paraumbilical incision. The retractor system was raised both to obtain a good exposure of the region of interest and to place three other trocars.

Cardiovascular and pulmonary monitoring

In all the patients, five hemodynamic and pulmonary values were recorded at the following time points: before the operation (T1); after anesthesia induction (T2); 5 min after laparotomy in the OC group, achievement of a 12-mmHg pneumoperitoneum in the PP group, and raising of the mechanical lifting arm in the AWL group, respectively (T3); and after 30 min from T3 (T4); after abdominal closure in the OC group, desufflation in the PP group, and LaparoTenser removal in the AWL group, respectively (T5).

Hemodynamic variables measured included mean arterial pressure (MAP): mmHg = systolic pressure-diastolic pressure /3 + diastolic pressure; heart rate (HR): beats/min; cardiac output (CO): l/min; cardiac index (CI): l/min/m^2 = CO/body surface area (BSA), stroke volume index (SVI): ml/beat/m^2 = CI/HR; central venous pressure (CVP): cmH_2O; systemic vascular resistances index (SVRI): dynes/s/cm^{-5}/m^2 = MAP-CVP/CI*80; mean pulmonary arterial pressure (MPAP): mmHg; pulmonary capillary wedge pressure (PCWP): mmHg; and pulmonary vascular resistances index (PVRI): dynes/s/cm^{-5}/m^2 = MPAP-PCWP/CI*80)]. Data were obtained by the Swan-Ganz catheter and thermodilution method, as appropriate, and PCWP was obtained with balloon wedged catheterism. Pulmonary data included peak inspiratory pressure (PIP): cmH_2O: end-tidal CO_2 pressure ($ETCO_2$): mmHg; CO_2 arterial pressure ($PaCO_2$): mmHg; and arterial pH.

Statistical analysis

Statistical analysis was performed using the BMDP statistical package (BMDP Statistical Software Inc., Los Angeles, CA, USA). The significance of differences between the proportions was analyzed with the chi-square test. One-way analysis of variance (ANOVA) was performed to investigate differences in clinical characteristics among the three groups, and ANOVA for repeated measures was used to check changes in hemodynamic and pulmonary variables both among the three groups and over time. One-way ANOVA for repeated measures was used to analyze changes over time within a group. Two-way ANOVA for repeated measures was used to verify differences both among groups and over time. Statistical analysis was performed considering the three groups, both as a whole and separately, comparing each group with the other two. The interaction rate among the three groups also was determined. For all data, the F ratio and associated p values were recorded. A p value less than 0.05 was considered significant.

Results

The clinical characteristics of the patients enrolled in this trial are shown in Table 1. Insertion of the Swan-Ganz catheter was always successful and free of complication. All the operations were successfully completed, and no major

Table 1. Clinical characteristics of patients undergoing cholecystectomy

	OC	PP	AWL	p^a
Gender M/F	3/2	4/1	4/1	0.71[b]
Age (years)				
Mean (SEM)	36.6 (2.7)	37.0 (2.2)	37.8 (2.2)	0.93
Range	30–45	31–44	32–45	
Body weight (kg)				
Mean (SEM)	72.2 (4.2)	71.8 (3.6)	73.4 (4.1)	0.95
Range	62–87	63–83	64–85	
Body height (cm)				
Mean (SEM)	168.1 (4.8)	171.2 (4.2)	170.8 (4.8)	0.86
Range	158–182	161–182	156–185	
BSA (m^2)[c]				
Mean (SEM)	1.82 (0.08)	1.84 (0.07)	1.85 (0.08)	0.95
Range	1.63–2.08	1.66–2.04	1.63–2.08	
BMI[d]				
Mean (SEM)	25.5 (0.48)	24.4 (0.31)	25.1 (0.47)	0.24
Range	23.9–26.5	23.41–25.2	24.0–26.3	
Intraoperative complications				
(yes/no)	0/5	1/4	1/4	0.56[b]
Operation time (min)				
Mean (SEM)	60 (1.6)	66 (4.8)	70 (4.5)	0.23
Range	55–65	60–85	60–85	
Postoperative complications				
(yes/no)	1/4	0/5	0/5	0.34[b]
Discharge (days)				
Mean (SEM)	5.2 (1)	1	1	0.0007[e]
Range	3–9	—	—	

[a] One-way analysis of variance (ANOVA)
[b] Chi-square test
[c] BSA, body surface area
[d] BMI, body mass index
BSA and BMI were obtained as follows:
body surface = 0.007184 × body weight(kg)$^{0.425}$ × body height(cm)$^{0.725}$
body mass index = body weight(kg)/body height(m) × body height(m)
[e] Significant difference; AWL/PP vs OC (p = 0.014 Student's t-test
OC, open cholecystectomy; PP, laparoscopic cholecystectomy with pneumoperitoneum; AWL, gasless laparoscopic cholecystectomy with LaparoTenser
SEM, standard error of mean

technical difficulties were encountered during laparoscopic procedures. The surgical field was well exposed both by pneumoperitoneum and abdominal wall lifting. Two patients (one in the PP group and one in the AWL group) had an episode of bleeding from the hepatic surface, which was controlled with coagulation. One patient in the OC group suffered from postoperative pneumonia, which resolved after appropriate medical therapy. Time to discharge was significantly longer for patients in the OC group.

Hemodynamic monitoring (Table 2)

Basal measurements (T1) showed no differences among the three groups. After induction of anesthesia (T2), a slight but significant impairment of cardiovascular functions was registered. Indeed, a decrease in systemic vascular resistance with reduction in the MAP, which was not counterbalanced by an increase in the heart rate, was observed after administration of anesthetic drugs. Tracheal intubation and pulmonary positive pressures were associated mainly with an increase in CVP, PCWP, and PVR, with a significant increase in the MPAP. As a consequence of such alterations, a slight decrease of the cardiac function, as measured by CO, CI, and SVI, was observed.

Table 2. Hemodynamic monitoring

Variable	T1[a]	T2[a,b]	T3[b,c]	T4[c]	T5
MAP (mmHg)	88.4	83.0	85.2	85.8	87.0
	86.8	82.6	98.4	99.4	88.6
	84.6	81.2	82.0	83.2	84.4
HR (beats/min)	86.0	81.2	82.4	81.4	80.4
	84.6	81.2	83.0	83.2	82.6
	82.6	80.4	81.2	80.2	79.6
CO (L/min)	5.9	5.3	5.5	5.6	5.8
	5.8	5.4	4.7	4.6	5.7
	5.7	5.4	5.4	5.5	5.6
CI (l/min/m^2)	3.28	2.92	3.06	3.12	3.20
	3.24	3.00	2.62	2.56	3.14
	3.18	2.98	3.06	3.12	3.16
SVI (ml/beat/m^2)	38.15	35.95	37.23	38.42	39.85
	38.50	37.12	31.70	30.88	38.15
	38.57	37.10	37.02	38.22	38.98
CVP (cm H_2O)	3.2	8.2	8.2	8.2	7.8
	3.4	8.4	16.8	17.8	8.4
	3.6	8.6	8.8	8.8	8.8
SVRI	2080.8	2055.0	2013.2	1990.8	1981.6
(dynes/s/cm^{-5}/m^2)	2060.2	1979.6	2494.2	2551.8	2045.2
	2035.4	1947.8	1950.6	1944.6	1950.2
MPAP (mmHg)	13.2	15.2	15.2	15.6	15.0
	13.0	15.0	22.2	22.4	15.2
	13.4	15.4	15.2	15.4	15.2
PCWP (mmHg)	5.8	6.6	6.8	7.0	7.0
	5.6	6.6	13.8	14.2	7.0
	6.0	7.0	7.0	7.4	7.2
PVRI	180.7	235.8	219.4	220.4	200.2
(dynes/s/cm^{-5}/m^2)	182.7	224.0	257.8	257.1	209.4
	186.4	225.7	218.7	209.6	206.5

Note: Values are expressed as mean. The three rows for each variable refer, top to bottom, to the OC group, PP group, and AWL group, respectively
[a] One-way analysis of variance (ANOVA) showed a significant difference between T1 and T2 within each group ($p < 0.05$)
[b] T2 and T3 were significantly different in the PP group ($p < 0.01$).
Note: Two-way ANOVA for repeated measures showed no differences between the OC and AWL groups in comparisons of serial changes over time
[c] For all the variables except HR and PVRI, significance was found among the PP group and the OC or AWL groups at T3 and T4 (p from 0.04 to 0.01)

After laparotomy (OC group) or LaparoTenser application (AWL group), it was shown that no hemodynamic parameters worsened further, tending to remain stable. Of interest, no differences were noted either between the OC and AWL groups or within the same group at T2, T3, T4, and T5. In brief, laparotomy and abdominal wall lifting were shown to have no effects on cardiovascular functions. On the contrary, in the PP group all values were demonstrated to differ significantly between T2 and T3, thus showing that pneumoperitoneum produced a critical impairment of cardiovascular functions.

During the intraoperative period, the 12-mmHg CO_2 pneumoperitoneum caused a significant increase in both systemic vascular resistance (from 1979.6 to 2551.8 dynes/s/cm^{-5}/m^2) and MAP (from 82.6 to 99.4 mmHg), with a difference of 25% and 20%, respectively. Cardiac function was impaired with 15% cardiac output as well as cardiac index and stroke volume reduction, whereas heart rate remained stable. A significant increase in pulmonary vascular resistance (15%) and mostly capillary wedge pressure (115%), was observed. Also, MPAP and CVP were increased, 49% and 111%, respectively. This trend was observed at T3, and worsened at T4.

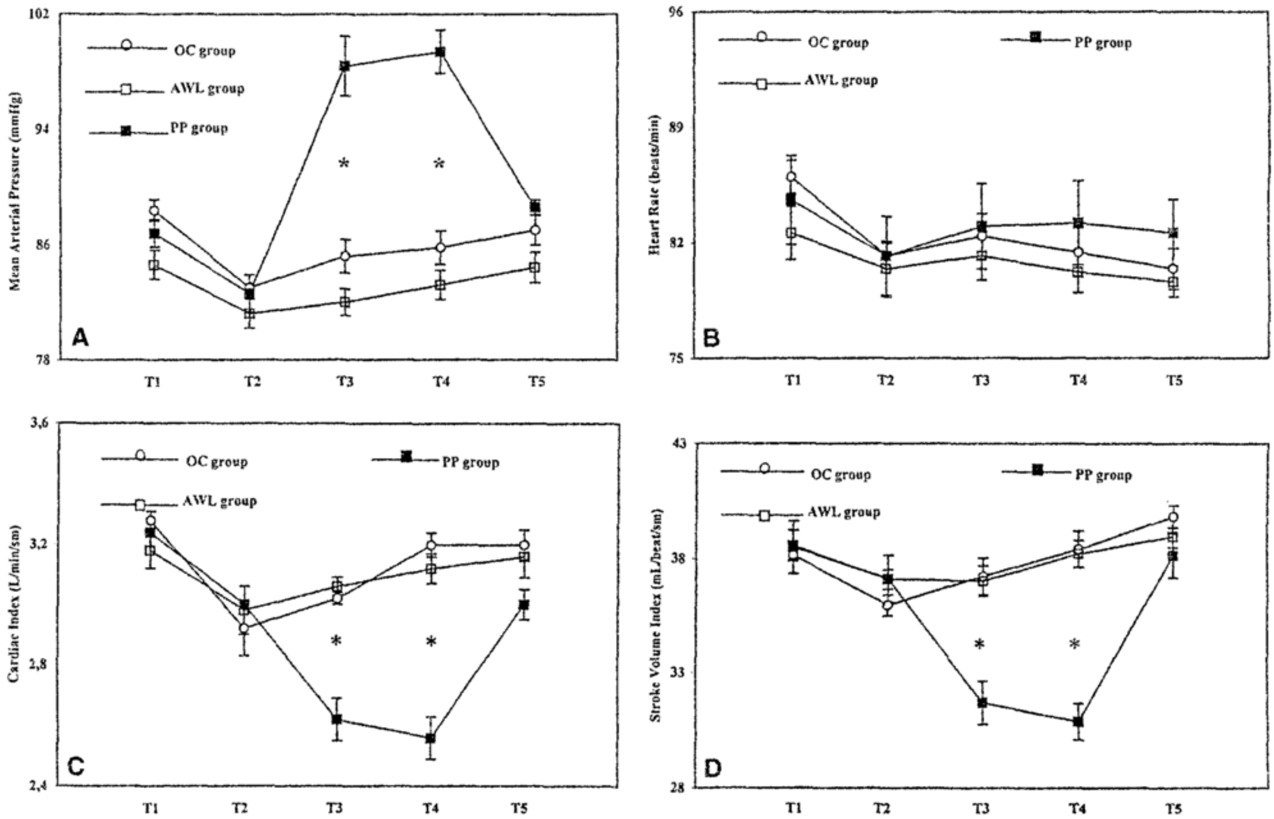

Fig. 1. Intraoperative monitoring of mean arterial pressure (**A**), heart rate (**B**), cardiac index (**C**), and stroke volume index (**D**) in patients undergoing cholecystectomy. OC group, open surgery (n = 5); PP group, CO_2 pneumoperitoneum (n = 5); AWL group, abdominal wall lifting (n = 5). T1/T5, intraoperative time points (see text). Values are mean ± SEM. In each group, anesthesia produced a significant reduction in MAP, HR, CI, and SVI (T1 and T2; one-way repeated measures ANOVA, $p < 0.05$). In the subsequent intraoperative periods, these variables tended to normalize in the OC and AWL groups without differences between the two groups. The PP group showed significant alterations with increased MAP and depressed CI and SVI (*$p < 0.05$, PP group vs other groups; two-way ANOVA for repeated measures). Heart rate was unaffected.

After desufflation, all figures returned to the values observed at T2. When the PP group was compared with the other groups, the statistical analysis showed significant differences between T3 and T4 for all the variables except the HR and PVRI values (Figs. 1 and 2). Because of figure complexity, data are not presented, but p values ranged from 0.04 to 0.01. However, cardiovascular functions were never critical because of the overall healthy condition of the patients enrolled in this study. Therefore, no therapeutic adjustments were needed. Therefore, which one intent of the study was accomplished: to gain as clear data as possible on cardiopulmonary changes during the procedures performed.

Pulmonary monitoring (Table 3)

After intubation, PIP and $ETCO_2$ could be recorded. Therefore, only $PaCO_2$ and pH values were available for the analysis of difference between T1 and T2. However, anesthesia and its related cardiovascular impairment did not produce any significant effects on these variables. Laparotomy and abdominal wall lifting were not associated with any substantial changes in PIP, $ETCO_2$, $PaCO_2$, and pH over time during the operative steps. Values were shown to be stable, and no differences were noted between two groups. On the contrary, CO_2 pneumoperitoneum was followed by a marked elevation of PIP (109%) and $ETCO_2$ (21%). At T3 and T4 $PaCO_2$ increased (27%), and this increase was accompanied by a marked decrease in pH (2%). Of interest, $PaCO_2$ rose more than $ETCO_2$, suggesting a difficult CO_2 elimination resulting from an increased pulmonary dead space. However, no attempts were made to compensate for these changes, and minute ventilation was held fixed. All values normalized after desufflation. The statistical analysis showed a significant difference among the PP, OC, and AWL groups during T3 and T4 ($p < 0.01$) (Fig. 3).

Discussion

The laparoscopic approach to many abdominal surgical diseases has become increasingly popular since it has been demonstrated to be a safe and reliable technique with several advantages over standard open procedures [9, 18]. As expected, the increasing use of laparoscopy has resulted in an increased number of elderly patients undergoing minimally invasive surgery, with an increased incidence of associated medical diseases, lengthened operation time, and higher surgical and anesthetic risks [5, 6].

Because laparoscopy requires an intraperitoneal working space, CO_2 at a pressure of 10 to 15 mmHg has been used traditionally for this purpose. Therefore, it is important

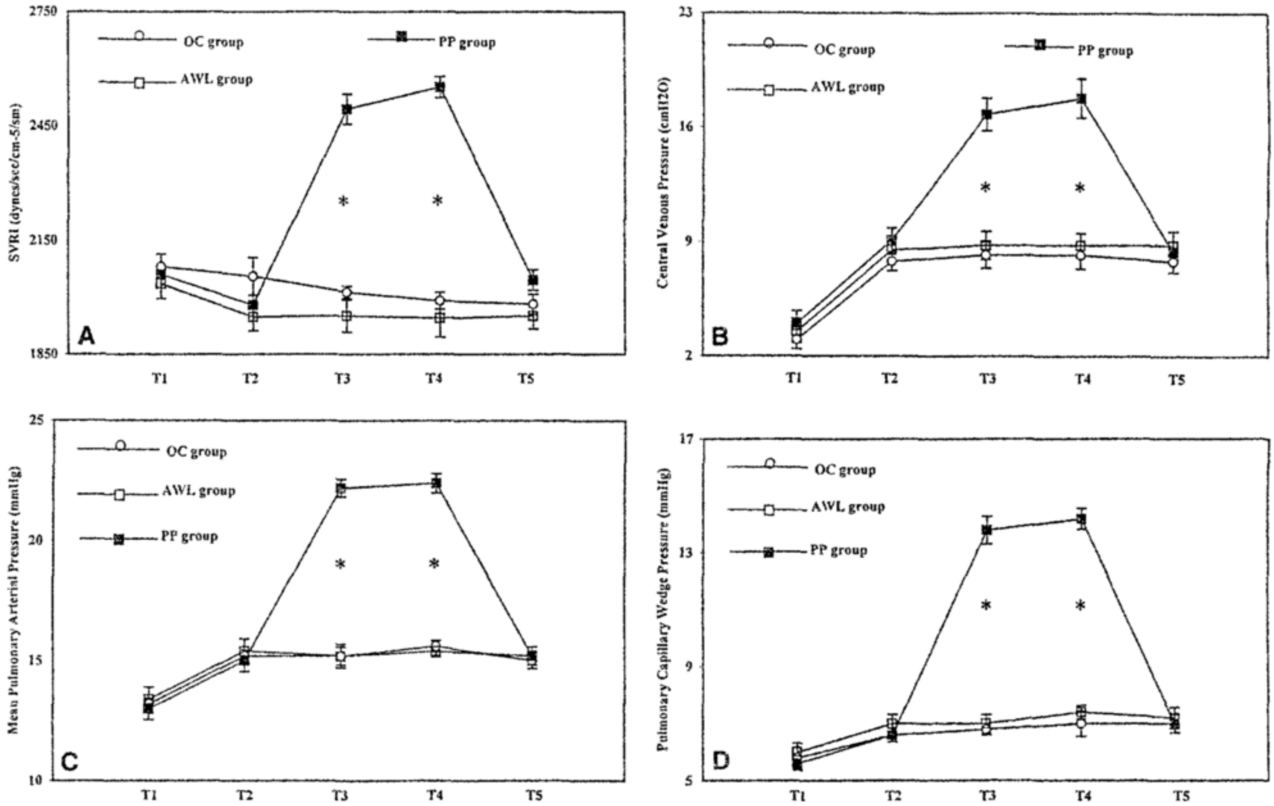

Fig. 2. Intraoperative monitoring of systemic vascular resistances index (**A**), central venous pressure (**B**), mean pulmonary arterial pressure (**C**), and pulmonary capillary wedge pressure (**D**) in patients undergoing cholecystectomy. OC group, open surgery (n = 5); PP group, CO_2 pneumoperitoneum (n = 5); AWL group, abdominal wall lifting (n = 5). T1/T5, intraoperative time points (see text). Values are mean ± SEM. In each group, anesthesia produced a significant reduction in SVRI and an increase in CVP, MPAP, and PCWP (one-way repeated measures ANOVA, $p < 0.05$). In the subsequent intraoperative periods, no differences were noted between OC and AWL patients. SVRI, CVP, MPAP, and PCWP were significantly increased in the PP group at T3 and T4 (*$p < 0.05$, PP group vs other groups; two-way repeated measures ANOVA).

to establish the true effects of pneumoperitoneum on the cardiovascular function and other physiologic functions [18]. Many experimental studies have demonstrated that CO_2 pneumoperitoneum may exert negative effects on cardiopulmonary, vascular, renal, and cerebral functions, and that it therefore is not very safe in patients with such underlying diseases, who in turn have been deemed as not ideal candidates for traditional laparoscopy [1, 7]. However, potentially harmful physiologic changes produced by CO_2 pneumoperitoneum have not been clarified, and results are still controversial. Moreover, at this writing, only a few studies have been performed in human beings [11, 19]. Therefore, we decided to compare CO_2 pneumoperitoneum with both abdominal wall lifting and standard open surgery to elucidate the effects of these three procedures on cardiopulmonary functions. In particular, the inclusion of the OC group was considered essential because it served as a control group for determining any changes in cardiopulmonary functions induced by surgical stress. For the same reason, it was deemed helpful to evaluate the influence of anesthesia by recording both the basal and postinduction levels of the parameters analyzed. To avoid misinterpretation of results, this trial was designed with the purpose to keep anesthetic parameters fixed during all operations. Therefore, all the enrolled patients had to be healthy, young ASA I class

Table 3. Pulmonary monitoring

Variable	T1	T2[a]	T3[a,b]	T4[b]	T5
PIP (cm H_2O)		17.8	18.0	17.8	17.8
		17.2	36.2	36.0	20.2
		18.0	18.0	18.2	18.2
$ETCO_2$ (mmHg)		29.0	28.4	28.2	29.2
		29.2	35.2	35.6	31.2
		29.8	29.2	28.8	29.6
$PaCO_2$ (mmHg)	36.0	36.0	35.4	35.6	36.0
	36.0	35.4	44.0	45.0	35.8
	36.0	37.4	36.0	35.8	35.6
pH	7.422	7.428	7.436	7.433	7.428
	7.428	7.436	7.341	7.331	7.431
	7.426	7.422	7.428	7.431	7.433

Note: Values are expressed as mean. The three rows for each variable refer, top to bottom, to the OC group, PP group, and AWL group, respectively. PIP and $ETCO_2$ were recorded after intubation

[a] One-way analysis of variance (ANOVA) for repeated measures showed a significant difference between T2 and T3 in the PP group ($p < 0.01$)

Note: Two-way (ANOVA) for repeated measures showed no differences between the OC and AWL groups in comparisons of serial changes over time

[b] Significance was found among the PP group and the OC or AWL groups at T3 and T4 ($p < 0.01$)

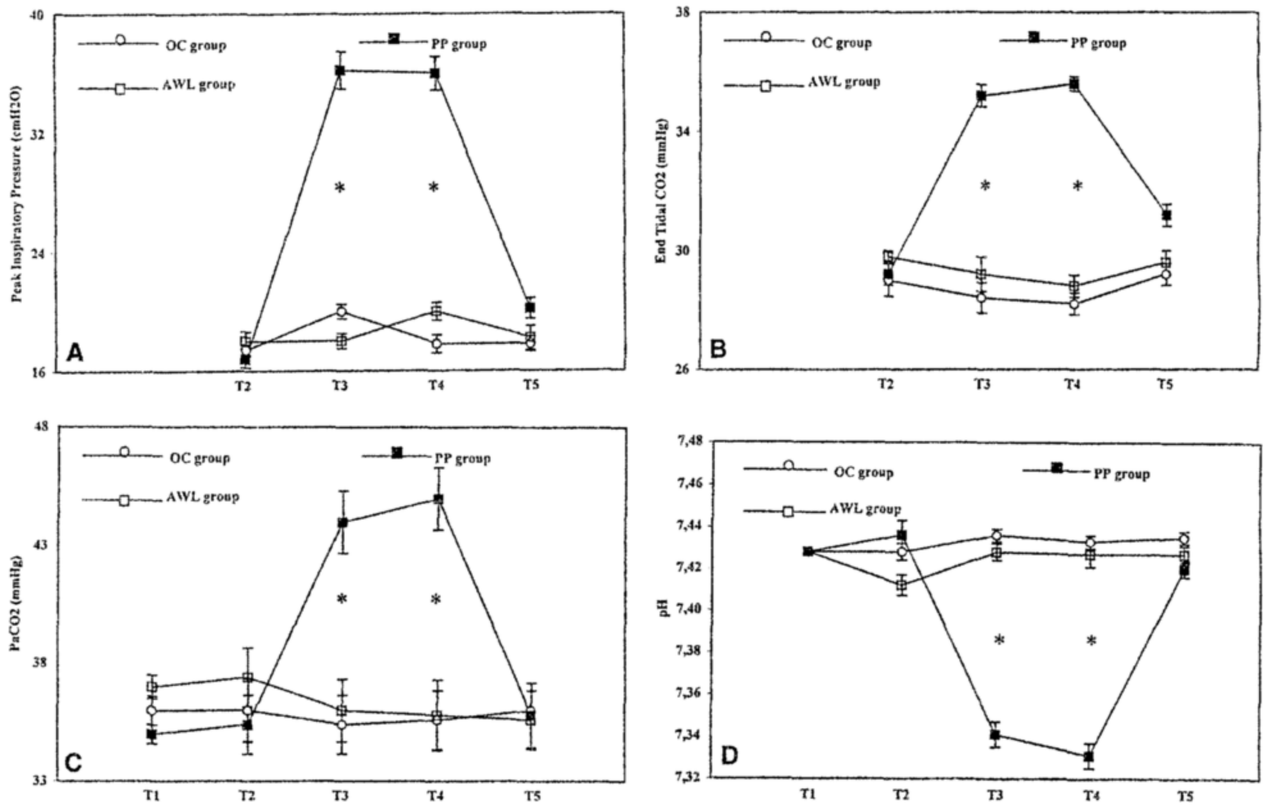

Fig. 3. Intraoperative monitoring of peak inspiratory pressure (**A**), end-tidal CO_2(**B**), $PaCO_2$(**C**), and arterial pH (**D**) in patients undergoing cholecystectomy. OC group, open surgery (n = 5); PP group, CO_2 pneumoperitoneum (n = 5); AWL group, abdominal wall lifting (n = 45). T1/T5, intraoperative time points (see text). Values are mean ± SEM. The OC and AWL groups showed no serial changes over time. A significant increase in PIP, $ETCO_2$, $PaCO_2$ with respiratory acidosis was recorded in the PP group ($^*p < 0.01$, PP group vs other groups; two-way repeated measures ANOVA).

surgical risks. Nevertheless, cardiopulmonary alterations were never so serious or long-lasting as to require pulmonary adjustments or cardiovascular drugs.

After induction of anesthesia, no critical but significant hemodynamic changes were recorded in the three groups. A decrease in systemic vascular resistance, most likely determined by the opening of small arterovenous shunts, as suggested by an increase in the CVP, was recorded. However, CVP elevation also followed modification of the respiratory physiology resulting from tracheal intubation and positive pulmonary pressures. The most relevant finding was a significant elevation of the right-side filling pressures with increased MPAP and pulmonary vascular resistance. An increased left preload (i.e., elevation of the pulmonary capillary wedge pressure) was not sufficient to avert a slight impairment of the cardiac function, as manifested by a 10% cardiac index and MAP lowering. Surprisingly, it was shown that the heart rate did not increase during this lowered cardiac output. Although in many reports a heart rate increase after anesthesia induction is well described, a slight bradycardia, probably related to the influence of the anesthetic drugs on brain cardiac centers, also has been reported [3].

Throughout the subsequent operative period, the hemodynamic alterations observed during induction of the anesthesia tended to be stable, with a slow but progressive trend to normalize in patients undergoing open or gasless cholecystectomy. On the contrary, CO_2 pneumoperitoneum was associated with a complex hemodynamic, pulmonary, and metabolic syndrome characterized by severe effects on blood flow, tissue perfusion, and pulmonary mechanics, as shown by CI decrease and elevation of MAP, SVRI, PCWP, and PIP. In addition, a respiratory acidosis with increased $ETCO_2$ and $PaCO_2$ was observed. Of note, these effects disappeared after desufflation.

Major problems with CO_2 pneumoperitoneum have been reported after an increase in intra-abdominal pressure and transperitoneal absorption of CO_2 [2, 5]. A high abdominal pressure is known to cause both increased catecholamine release and urinary output reduction. The latter is believed to result from direct renal compression and renal vein hypertension, with release of angiotensin II and vasopressin [13]. Although these hormone levels were not measured in this study, cardiopulmonary changes likely were determined by their effects, resulting in an increased SVRI with MAP elevation, a significantly reduced cardiac output, and an increased pulmonary capillary wedge pressure. In addition, respiratory acidosis could have worsened the situation by increasing catecholamine release and reducing myocardial contractility. Hypercarbia-induced vasoconstriction could have contributed as well [3]. Diaphragm lifting by the increased intra-abdominal pressure caused an increase in the elastance and resistance of the respiratory system, as shown by the significant PIP elevation. The subsequent derangement of pulmonary mechanics with increased thoracic pressures was responsible for the elevation of both pulmonary vascular resistance and mean pulmonary arterial pressure [10]. However, increased PVRI could follow respiratory acidosis and reduction of cardiac function. The higher intra-abdominal and intrathoracic pressures, together with pulmonary hypertension and urinary output reduction, determined an increased CVP. The eventual hemodynamic picture was a cardiac and pulmonary impairment with increased left- and right-side filling pressures. As stated, hypercarbia with subsequent respiratory acidosis might have contributed to these cardiopulmonary changes [9]. Of note, the increased $PaCO_2$ to $ETCO_2$ ratio reflected an increased pulmonary dead space during CO_2 pneumoperitoneum. Correction of this alteration should be pursued by increasing the tidal volume, because any increase in the respiratory rate could worsen the acidosis by increasing the pulmonary dead space [3].

The presence of the control (OC) group permitted evaluation of the effects that both the anesthesia and different surgical procedures had on cardiopulmonary functions. The lack of any differences between the OC and AWL groups in any of the variables analyzed suggests that gasless laparoscopy did not produce more significant hemodynamic and pulmonary changes than surgical stress.

Because of different eligibility criteria, monitoring systems, and types of subjects enrolled (human beings or animals), it is very difficult to compare the current results reported in the literature. In agreement with our results, some authors reported that gasless laparoscopy had no adverse effects on cardiopulmonary functions [6, 7]. On the contrary, other authors even found positive effects [9, 20] or no differences with respect to CO_2 pneumoperitoneum [16]. According to our experience with invasive monitoring, the LaparoTenser did not seem to have any positive or negative effects on cardiac and respiratory functions. In particular, our data have not shown any reduction in the pulmonary pressures and subsequent improved cardiac function, which have been reported with the use of other abdominal wall lifting devices [1]. On the other hand, the LaparoTenser did not produce any stress to the abdominal wall musculature favoring catecholamine release with SVRI increase and lowered cardiac output, as reported with the use of Laprolift [20], and this could be a real advantage of this system [2].

In conclusion, anesthesia induced hemodynamic and pulmonary changes, but these effects tended to normalize over the operative time. Carbon dioxide pneumoperitoneum was associated with an important cardiac and pulmonary impairment, which should be considered in patients with underlying diseases. The potential postoperative benefits of laparoscopy must be weighed against the risk associated with a longer anesthesia and cardiopulmonary alterations. In high-risk patients, gasless laparoscopy should be preferred because it was shown to be a reliable technique, to share the same advantages of the traditional laparoscopic approach, and not to induce any changes in cardiopulmonary functions.

Acknowledgments. The authors thank Dr. Ciro Romano, MD, PhD (Division of Internal Medicine, "F. Magrassi" Department of Clinical and Experimental Medicine, Second University of Naples School of Medicine, Naples, Italy) for linguistic review of this article.

References

1. Carry PY, Gallet D, Francois Y, Perdrix JP, Sayag A, Gilly F, Eberhard A, Banssillon V, Baconnier P (1998) Respiratory mechanics during laparoscopic cholecystectomy: the effects of the abdominal wall lift. Anesth Analg 87: 1393–1397
2. Cuschieri A (1998) Adverse cardiovascular changes induced by positive pressure pneumoperitoneum: possible solutions to a problem. Surg Endosc 12: 93–94 DOI: 10.1007/s004649900604
3. Feig BW, Berger DH, Dougherty TB, Dupuis JF, Hsi B, Hickey RC, Ota DM (1994) Pharmacologic intervention can restablish baseline hemodynamic parameters during laparoscopy. Surgery 116: 733–741
4. Gutt CN, Daume J, Schaeff B, Paolucci V (1997) Systems and instruments for laparoscopic surgery without pneumoperitoneum. Surg Endosc 11: 868–874 DOI: 10.1007/s004649900474
5. Horvath KD, Whelan RL, Lier B, Viscomi S, Barry L, Buck K, Bessler M (1998) The effects of elevated intraabdominal pressure, hypercarbia, and positioning on the hemodynamic responses to laparoscopic colectomy in pigs. Surg Endosc 12: 107–114 DOI: 10.1007/s004649900608
6. Kawamura YJ, Sawada T, Sunami E, Saito Y, Watanabe T, Masaki T, Muto T (1999) Gasless laparoscopically assisted colonic surgery. Am J Surg 177: 515–517
7. Koivusalo AM, Kellokumpu I, Ristkari S, Lindgren L (1997) Splanchnic and renal deterioration during and after laparoscopic cholecystectomy: a comparison of the carbon dioxide pneumoperitoneum and the abdominal wall lift method. Anesth Analg 85: 886–891
8. Mathew G, Watson DI, Ellis TS, Jamieson GG, Rofe AM (1999) The role of peritoneal immunity and the tumor-bearing state on the development of wound and peritoneal metastases after laparoscopy. Aust N Z J Surg 69: 14–18
9. McDermott JP, Regan MC, Page R, Stokes MA, Barry K, Moriarty DC, Caushaj PE, Fitzpatrick JM, Gorey TF (1995) Cardiorespiratory effects of laparoscopy with and without gas insufflation. Arch Surg 130: 984–988
10. Moncure M, Salem R, Moncure K, Testaiuti M, Marburger R, Ye X, Brathwaite C, Ross SE (1999) Central nervous system metabolic and physiologic effects of laparoscopy. Am Surg 65: 168–172
11. Ninomiya K, Kitano S, Yoshida T, Bandoh T, Baatar D, Matsumoto T (1998) Comparison of pneumoperitoneum and abdominal wall lifting as to hemodynamics and surgical stress response during laparoscopic cholecystectomy. Surg Endosc 12: 124–128
12. Nishio S, Takeda H, Yokoyama M (1999) Changes in urinary output during laparoscopic adrenalectomy. Brit J Urol 83: 944–947
13. Ogihara Y, Isshiki A, Kindscher JD, Goto H (1999) Abdominal wall lifting versus carbon dioxide insufflation for laparoscopic resection of ovarian tumors. J Clin Anesth 11: 406–412
14. Ramachandran CS, Arora V (1998) Two-port laparoscopic cholecystectomy: an innovative new method for gallbladder removal. J Laparoendosc Adv Surg Tech A 8: 303–308
15. Sampietro R (1999) Correct use of the gasless LaparoTenser system. Surg Endosc 13: 316 DOI: 10.1007/s004649900978
16. Schulze S, Lyng KM, Bugge K, Perner A, Bendtsen A, Thorup J, Nielsen HJ, Rasmussen V, Rosenberg J (1999) Cardiovascular and respiratory changes and convalescence in laparoscopic colonic surgery: comparison between carbon dioxide pneumoperitoneum and gasless laparoscopy. Arch Surg 134: 1112–1118
17. Shoemaker WC, Wo CC, Bishop MH, Thangathurai D, Patil RS (1996) Noninvasive hemodynamic monitoring of critical patients in the emergency department. Acad Emerg Med 3: 675–681
18. Takagi S (1998) Hepatic and portal vein blood flow during carbon dioxide pneumoperitoneum for laparoscopic hepatectomy. Surg Endosc 12: 427–431 DOI: 10.1007/s004649900696
19. Vezakis A, Davides D, Gibson JS, Moore MR, Shah H, Larvin M, McMahon MJ (1999) Randomized comparison between low-pressure laparoscopic cholecystectomy and gasless laparoscopic cholecystectomy. Surg Endosc 13: 890–893 DOI: 10.1007/s004649901127
20. Woolley DS, Puglisi RN, Bilgrami S, Quinn JV, Slotman GJ (1995) Comparison of the hemodynamic effects of gasless abdominal distension and CO_2 pneumoperitoneum during incremental positive end-expiratory pressure. J Surg Res 58: 75–80